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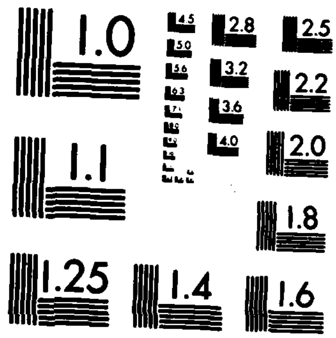
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TRANSIENT EVOKED POTENTIAL

IN A CRITICAL EVENT DETECTION TASK

THESIS

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

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Abstract

An experiment was designed to investigate late positive components of the transient evoked potential elicited by detection of a perceptually complex critical event. Areas of investigation included spatial distribution, motor response effects, stimulus duration effects, possible contingent negative variation effects, components of the event which immediately preceded the critical event, and value as a workload metric. Subjects watched a series of visual stimuli presented on a video screen. Each stimulus was a pattern of seven binary digits in a single row. Periodically, the number of consecutive ´1´s in the pattern built up to four. Four consecutive ones indicated a critical event. Subjects were instructed to depress a button when they detected a critical event. Electrodes recorded EEG at the parietal, central, and frontal midline scalp locations with opposing mastoids used for reference and ground. Reaction times and response accuracy were also recorded.

Though equipment failure precluded any significant statistical analysis, descriptive observations of the data provided useful guidance for fututre research. A prominent, positive component in the P500 latency range

was elicited by the critical event stimulus. Its spatial distribution generally showed a parietal maximum and a frontal minimum. The additional presence of a P300 appears possible but could not be confirmed. The prominent P500 component became less apparent when stimulus duration approached the 1.5 to 3.0 second interstimulus interval. No significant contingent negative variation, motor response, or preceding event effects were observed.

The critical event was also presented as a secondary task combined with each of three primary tasks: tracking, mental math, and probability monitoring. Performance scores, reaction times, and evoked potentials indicated the critical event detection task, as presented, was too intrusive to be a useful workload metric.

TRANSIENT CORTICAL EVOKED RESPONSE IN A CRITICAL EVENT DETECTION TASK

I Introduction

Backround

In modern military conflicts, the side with the greater capability to process large volumes of information quickly and accurately gains a decisive advantage. This advantage is all the more crucial for a force which is numerically outnumbered. This being the case, much has been accomplished to advance the machine components of military information processing in the armed forces of the United States. Nevertheless, a "bottleneck" of throughput remains at the point of human intervention. Advances in man-machine information interfaces represent relatively untapped potential for significant improvements in the technical conduct of war. Systems must be designed to maximize human information processing capacities and compensate human limitations. To achieve such designs, more data are needed about how the brain organizes and processes information and what it can and cannot do. A system's warfighting capability will be maximized only when the division of tasks and method of interface between man and machine are optimized.

Effective management of mental workload is another critical concern in the successful design and deployment of modern military systems and manned space systems in particular. Military operations in space rely on systems which incorporate some of the most advanced technology available from the engineering disciplines. Such increases in technical complexity often bring commensurate increases in the monitoring, control, and decision-making responsibilities for the system operators. But the information processing capacities of human operators are comparatively limited. Approaching or exceeding them can seriously jeopardize overall system performance. In addition to the technical complexity of the tasks, operator capacities can be further influenced by multiple stressors in the working environment. Fatigue, sleep loss, weightlessness, and a number of other chemical and biological factors may cause significant losses of perceptual, cognitive, and motor capacity. Finally, military operations with rapidly changing tactical situations, quick response times, and frequent emergencies are more susceptible to human failure with potentially catastrophic results (1:1).

Careful attention to crew capabilities throughout all phases of space system development and operational life is of critical importance to mission success. Not only the design features of the crew station but more general questions of system capacity, deployment, and manning

require accurate and reliable measures of human cognitive information processing and mental workload. At present, there are no commonly accepted measures of either. The engineer assigned to the cognitive processing/workload evaluation problem may choose one or more suggested metrics from the physiological, behavioral, or subjective domains. But there may be little guarantee that any chosen metric is appropriate to the task or that it measures the true information processing capacities of the human operator. Two research thrusts are currently in progress to redress these problems. One seeks to develop a functional model of the human information processing system with its capacities and limitations. The other seeks to develop useful measures of mental workload (2:648).

Recent research suggests that human workload capacities may function as independent resource pools individually tapped by specific tasks (3). As a consequence, the U.S. Air Force is in the process of constructing a set of well-defined tools to measure various aspects of mental workload. Broad, non-specific measures such as subjective opinion give an overall assessment of workload to identify "chokepoints." For example, operators may find a given tasks very difficult to perform. This "chokepoint" can then be analyzed in detail using more refined subjective, behavioral, and physiological measures (4:1).

One of the physiological measures under consideration for use in detailed workload analysis is the transient cortical evoked response, also referred to as the event-related brain potential (ERP). The transient cortical evoked response is typically obtained by adding the electroencephalograms (EEGs) for the same time-locked epoch following several identical stimuli. The stimulus-related voltages add linearly and stand out from the non-stimulus-related voltages which add only as the root mean square (RMS). The resulting waveform consists of a number of large positive and negative peaks. An ideal, generic represenatation of a visual evoked response waveform is shown in Fig 1. Under appropriate experimental conditions, these peaks or components are consistent within an individual and identifiable across individuals. The peaks are classified according to their polarity and latency (time delay in milliseconds after stimulus presentation). For example, an N120 component is so labeled because it is a negative peak that occurs consistently at about 120 milliseconds following stimulus presentation. Components within 250 milliseconds of the stimulus are thought to reflect the exogenous or sensory input functions of the brain. Later components are thought to reflect the endogenous or cognitive and response decision functions (4:3). Only a few of the waveform components are widely accepted. One of the most prominent and consistent of the endogenous components is

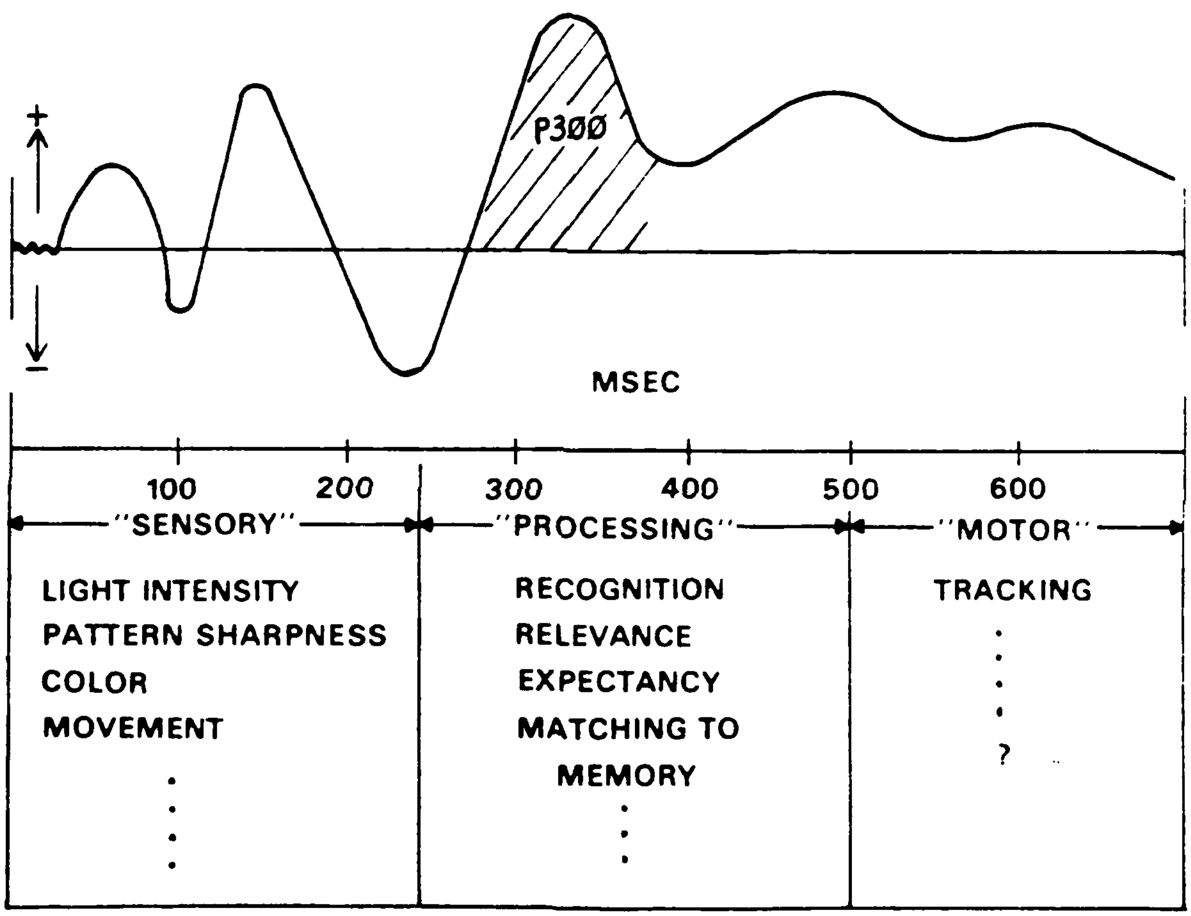


Fig 1. Generic Visual Evoked Response Waveform

the P300 (a positive peak about 300 milliseconds after stimulus presentation). The P300 is also referred to as the P3 (third significant positive peak). Experiments by O'Donnell and others have established that the P3 is sensitive to memory load. When memory load is systematically increased a corresponding systematic decrease in the amplitude of the P3 component is observed. One speculation suggests that as cognitive capacities are increasingly exhausted, the underlying cortical generators of the P3 are correspondingly less available (4:3).

Another procedure which may prove useful in workload assessment is referred to as the oddball paradigm, originally developed by Donchin and his associates. In the oddball paradigm, subjects are presented with two simple stimuli in a Bernoulli sequence. The amplitude of the P3 elicited turns out to be inversely proportional to the subjective probability of the stimulus. Experimenters have found that the prominent P3 component generated by the less frequent stimuli may be used to index the brain's central processing activity independent of motor behavior (4:4,5).

The Workload and Ergonomics Branch of the Air Force Aerospace Medical Research Laboratory (AFAMRL) at Wright-Patterson Air Force Base is currently conducting studies to probe the use of transient cortical evoked responses to measure certain cognitive aspects of workload. Israel, Wickens, Chesney, and Donchin (1980)

found the P3 ERP component systematically reflected workload differences in a display-monitoring task and covaried inversely with reaction time under certain experimental conditions (5). Since then, other studies tested P3 sensitivity over a wide variety of experimental conditions and tasks. Since monitoring a display for some critical event is a common task in military command and control environments, Wilson, Ward, and Hann probed the use of ERP components to register the brain's detection of a critical event. Two major Air Force-related concerns influenced Wilson, Ward, and Hann's decision to investigate the the use of transient evoked response techniques in a command and control setting:

(1) The tasks required of the personnel who operate military command and control facilities are important and increasingly complex. Most ERP research involves very simple sensory inputs such as a single tone or display of a single character, whereas military command and control facilities usually require operators to monitor more complex events.

(2) In a typical command and control environment, one of the primary operator tasks is to detect critical events as soon as they occur. Research with infrequent stimuli suggested that ERPs might be a sensitive measure of critical event detection. Evoked response techniques may have unique value in measuring brain response to information displays without requiring an overt behavioral

response (6:20).

Wilson, Ward, and Hann used a stimulus consisting of seven digits in a single row forming a pattern of 0´s and 1´s. The patterns were presented every 2.5 to 3.5 seconds. A critical event was defined to occur when four consecutive 1´s appeared among the seven digits. The block of events ended with the critical event. If the block contained no critical event, it ended after the tenth pattern. In any block of events the critical event was presented either sequentially, randomly, or not at all. Sequential presentation meant that the two events preceding the critical event contained two and then three consecutive 1´s building up to the critical event. The task required the subject to push a button with one hand if the stimulus did not contain a critical event and a different button with the other hand if the stimulus indicated a critical event. This allowed the correlation of reaction time while controlling the interference of motor-related activity (6:20).

The resulting ERP waveform plots showed four prominent peaks at N200, P375, N425, and P525. Statistical analysis showed that the P525 occurred significantly later with a significantly larger amplitude for critical event trials than for non-critical event trials. Furthermore, P525 for the sequential critical event showed a larger amplitude than the random critical event. The P3-like peak at P375 did not show a

significant difference between experimental conditions (6:21,22).

Mean reaction times for critical event trials took about 100 milliseconds longer than non-critical event trials. Subjects also took longer to react to the random critical events than the sequential critical events. In addition, the trials which immediately preceded the sequential critical event trial (consisting of three consecutive 1's) had a significantly longer response time than the trial which immediately preceded the random critical event trial. Wilson, Ward, and Hann concluded (1) that the critical event significantly increased the reaction time and (2) the trial preceding the sequential critical event increased processing time required to determine whether the critical event had occurred. They also noted that although the reaction time differed significantly for the trial preceding the sequential critical event, the evoked response did not differ significantly from non-critical events (6:22).

The feature of interest found by Wilson, Ward, and Hann is the very prominent P525 peak which clearly indicated the occurrence of a critical event. This feature may prove to be useful in workload studies but further research is required to better characterize the P525 component. The first area of need is to determine that the experiment can be replicated to produce the same characteristic ERP components. Since Wilson, Ward, and

Hann used only one electrode placed over the parietal region of the brain (see Fig 2. Diagram of Electrode Locations), the second need is to measure the evoked responses with at least three electrode placements to determine the spatial distribution. The spatial distribution may then be used to aid in classification of the ERP components. Thirdly, since the critical event always ended the block, it is possible that the subject's relaxed level of arousal contributed to the ERP components observed by Wilson, Ward, and Hann. ERP components have proven to be sensitive to such changes which particularly complicate the interpretation of late ERP components (7:511). Fourthly, Wilson, Ward, and Hann purposed to use a very uncomplicated presentation defering the need to examine more real-world-like stimulus presentations and tasks to later studies (6:3). Finally, the P525 may be a sensitive measure of workload in certain tasks and not others. To be an effective workload metric, research is needed to identify the types of mental tasks the P525 is able to sensitively measure.

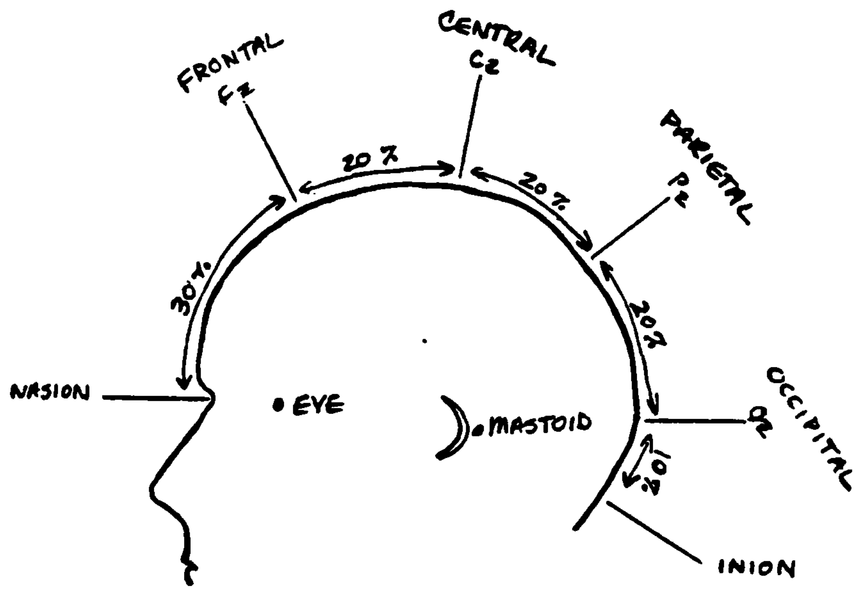


Fig 2. Diagram of Electrode Locations

Problem

The Air Force is in the process of developing a reliable and versatile battery of workload metrics. Late positive components of the transient evoked response have proven to be sensitive measures of mental workload under certain experimental conditions. Wilson, Ward, and Hann observed a large P525 component using a perceptually complex critical event. The experiment has not been replicated and the observed components could not be classified using their spatial distribution since evoked responses were recorded at only one electrode location. More information is needed about this P525 component to further define its characteristics, evaluate its usefulness as a non-behavioral measure of cognitive events, establish its robustness in more realistic display presentations, and assess its functionality as a workload metric.

This study will seek to answer the following questions:

(1) Can the prominent ERP components observed by Wilson, Ward, and Hann be replicated?

(2) What is the spatial distribution of these prominent ERP components with reference to the parietal, central, and frontal midline scalp locations?

(3) Are the prominent components observed when the presentation of stimuli does not stop after a critical

event?

(4) Are the prominent components observed when the no motor response is required?

(5) How does the P3 component recorded in previous visual "odd-ball" paradigms for a stimulus with overall probability of .20 compare to the late positive components for the critical event in this experiment?

(6) Are the ERP components sensitive to differences in difficulty of a primary mental task when the the same stimuli are presented as secondary tasks?

(7) To what degree do the observed ERPs for the secondary task stimuli correlate with behavioral indicators of workload such as reaction time and primary task performance?

(8) Does the event which contains three consecutive ones and precedes the critical event elicit ERP components which differ from those elicited by other non-critical events?

(9) Can this method be used to monitor critical event detection when the duration of the stimulus is increased to simulate a continuous display more typical of real-world, command and control hardware?

Objectives

This study will seek to define additional characteristics of the ERP components observed by Wilson, Ward and Hann. The characteristics of interest described in the objectives will help classify the ERP in terms of current research and assess its value as a measure of cognitive information processing:

(1) Replicate aspects of Wilson, Ward, and Hann´s experiment to determine if the same ERP components are observed.

(2) Determine the spatial distribution of prominent ERP components for a perceptually complex critical event with reference to the frontal, central, and parietal midline scalp locations. The hypothesis is that the P525 will show a central-parietal maximum with a spatial distribution similar to late P300 components.

(3) Observe how the prominent ERP components are affected when the block presentation does not end after each critical event. The hypothesis is that the P525 component will again be observed because it is primarily related to the stimulus processing. Limiting the effect of a general decline in the level of mental arousal following the critical event should give a more accurate ERP.

(4) Determine if the ERP components reliably indicate critical event detection when the duration of the

stimulus is incrementally increased to simulate a continuous digital display more characteristic of those used in real-world command and control environments. The hypothesis is that as the stimulus duration increases additional uncontrolled factors (like eye movements, continuous input, and changes in processing strategies) will nullify any ERP components which reliably indicate critical event detection.

(5) Measure the sensitivity of the ERP components to two levels of difficulty in a primary task, when the critical event is presented as a secondary task. The assumption is that the amplitude of the P525 component indicates a mental resource that must be shared when a primary task uses the same resource. In such a condition, an increase in the difficulty of the primary task should be indicated by a decrease in the amplitude of the P525 ERP. Accomplish the above measurement for three primary tasks requiring different mental skills to determine which skills may be indexed by the critical event ERP components. The assumption is that the critical event task draws more heavily from visual perceptual encoding and central information processing resources than from output/response resources. Hence, a primary task loading visual perception or information processing skills will decrease the amplitude of the P525 more than a task loading motor output skills.

(6) Observe how the ERP components for the same

stimulus are affected when no motor response is required. Again, the hypothesis is that the P525 is a function of stimulus processing rather than motor response initiation.

Scope

This study will seek to provide preliminary information about the usefulness of the P525 component as a possible measure of cognitive activity, a workload metric, or a tool for further studies of human information processing. Much more research will be needed to sufficiently characterize the ERP for use as a metric. The results of this experiment will aid in deciding whether such an effort should be undertaken.

II P300 Component Theory

Transient Evoked Potentials

Evoked potentials are a special form of electroencephalogram (EEG) measurement. EEGs measure the variation over time of electrical potentials on the scalp. Ordinarily, the continuous measurement of scalp potentials produces a waveform which appears to contain a great deal of random noise. Transient evoked potentials attempt to measure the brain's transient response to a particular stimulus. They are measured within a defined window of time (or epoch) during and immediately following a stimulus to determine how the scalp electrical potential changes as the brain processes the stimulus. Measurement and analysis of these transient cortical evoked potentials may offer valuable insights into how humans process information.

A number of formidable problems, assumptions, and limitations accompany the use of transient evoked potentials to monitor brain activity. A major problem is noise. The evoked potential from a single stimulus is at best 10 microvolts in magnitude. As such, it is masked by constant EEG "noise" which typically varies between 50 and 100 microvolts in amplitude. For a quarter century now researchers have employed a technique called signal averaging borrowed from World War II British radar

operators to partially overcome the noise problem (8:52). The same stimulus is presented numerous times during the course of an experiment. By "locking" the EEG measure to the time of stimulus presentation, the scalp potentials immediately following each stimulus may be added together. As tracings from numerous trials are added , the portions of the waveform elicited by the stimulus accumulate more rapidly where consistently positive and negative amplitudes overlap in time.

Even if the stimulus-related portion of the waveform is reliably obtained, there is still a question of what constitutes a valid interpretation of it. A major assumption is that EPs recorded from the scalp reflect intracranial activity. In other words, it is neural activity which contributes to the distinctive features of the EP waveform. Ruchkin emphasizes that a major "difficulty lies in the complexity of the signal" (8:56). The waveform is a very general measure and its underlying generators overlap in time and scalp location. The lack of common terminology and standards for experimental and analytical methodology have complicated efforts to define the evoked potential waveform. A widely accepted labeling convention locates the peak of a waveform component by its latency and polarity. Latency is a measure of the time interval expressed in milliseconds (ms) from stimulus presentation to the peak of the ERP component. The polarity designation precedes the latency designation and

is either positive (P) or negative (N). Common early components (latencies under 250 ms) have been identified, but later components are less consistent and correspondingly less agreed on. Helpful statistical procedures like principal component and discriminant analysis are increasingly used to extract independent factors which overlap in contribution to the evoked potential waveform (EP). Even so, emerging discoveries of new EP components have outnumbered and outpaced the follow-on experiments needed to test their validity. Even fewer attempts are made to determine their function in human information processing (10:159). Hence, this study is an attempt to follow up what appears to be the discovery of a new or at least different EP component. As a consequence of its uniqueness, the theoretical issues which relate to the P525 component will be borrowed from P300 theory.

Basics of the P300

Of the commonly observed EP components, the P300 is the most relevant to the objectives of this study by virtue of its similarity to the P525 in lateness, polarity, and changes in amplitude. It appears as a large positive peak at about 300 ms after the stimulus in a variety of experimental situations. Furthermore, the amplitude of the P300 is relatively unaffected by the

particular physical properties of the stimulus. The P300 following a high-frequency tone, for example, is identical to the P300 which follows a low-frequency tone. In fact, auditory, visual, and somatosensory stimuli all elicit a similar P300 component. The important factors influencing amplitude of the P300 are related to the informational context of the stimulus rather than the physical properties of the stimulus itself (7:508). For this reason, it is commonly accepted that the P300 reflects exogenous processes in the cognitive domain.

A considerable body of literature traces the efforts of reseachers to explain the significance of the P300. For example, according to Dr. Begleiter, the P300 measures "how significant a stimulus is to a subject" (8:56). But P300s observed in different experiments vary in latency from 210 ms to as late as 550 ms (Ref 1:507) and what they measure may be far more complex. In fact, many researchers now refer to this late component as an event-related potential (ERP) because it is invoked by the stimulus only in the context of certain instructions. Furthermore, evidence is mounting that the P300 itself may not be a unitary component, but a late positive complex (LPC) of overlapping components (7:506).

Most of the literature that undertakes to explain the P300 phenomenon attempts to integrate the experimental variables which have shown significant positive or negative correlation with the size of the P300 component.

Walter S. Pritchard summarizes the state of P300 literature when he says:

> Many of the variables that have been associated with P300 are more correlational in nature than theoretical. In a typical P300 experiment, a directly observable variable is manipulated, and resultant changes in P300 amplitude or latency are measured (7:507).

Researchers now agree that at least two fundamental variables account for the variance in P300 amplitude: subjective probability and task relevance (9:264).

Correlates of P300 Amplitude

One of the first variables to be associated with the P300 was stimulus probability. Sutton's original P300 research established an inverse relationship between stimulus probability and P300 amplitude (10:1187-88). Other early P300 researchers attempted to carry stimulus probability a step further by relating P300 amplitude to uncertainty resolution as defined in information theory. The information content of any stimulus (H) could be calculated precisely from the stimulus probability (p) using the formula:

$$H = \log_2 (1/p)$$

The hypothesis was that P300 amplitude should correlate

with the information content of the stimulus. And indeed, a number of researchers demonstrated that even the absence of a stimulus resulted in a P300 when the absence carried information to the subject (7:508,509). Johnston and Holcomb found that as subjects learned to derive information from a stimulus, its P300 amplitude increased (11:396-400). But limitations in information theory became apparent. Sutton had noted earlier that the inverse relationship between stimulus probability and P300 amplitude continued even when subjects were told in advance any relevant information contained in the stimulus (10:1187-1188). Plots of the bit information content of a stimulus failed to predict P300 amplitude any better than stimulus probability alone. Cambell, Courchesne, Picton, and Squires found that increases in in stimulus information above two bits did not necessarily invoke a parallel increase in P300 amplitude (12:45-68). Furthermore, Jenness found that a stimuli associated with rewards invoked higher P300 amplitudes than the same stimuli not associated with rewards (13:75-90). The definition of information provided by information theory does not account for the subjective value of the information. Classical information theory provides an inadequate theoretical basis for P300 research (7:509).

More recent experiments have shown that the calculated a priori probability of the stimulus does not predict P300 amplitude as closely as do the subjective

probability each subject assigns to stimulus outcomes beforehand and the confidence level they have in their perception of the stimulus (7:514,516). Roth, Ford, and Kopell associate P300 amplitude with two major factors. One is the amount of information received in the stimulus. They defined the amount of information as a function of the a priori uncertainty of the event´s occurence minus information loss due to the a posteriori uncertainty of having correctly perceived it. The other factor is attention required by task relevance (14:21).

The P300 cannot be considered a correlate of channel attention, because not all stimuli in the attended channel invoke P300s. Low-probability stimuli in the attended channel invoke P300s. High-probability stimuli in the attended channel do not. The requirement that the stimulus be task relevant suggests that selective attention is a necessary but not a sufficient condition for invoking the P300 (7:511).

Donchin defines the task relevance of a stimulus by how much it allows the subject to resolve uncertainties that must be resolved to correctly and quickly accomplish the assigned task (15:506). Researchers have observed that prominent P300 amplitudes are elicited by stimuli which are relevant to the assigned task. Whereas prominant P300s do not appear when the same stimuli are not task relevant. Task relevance appears to be a key determinant of P300 amplitude. In most cases, the

stimulus must be task relevant in order to elicit a P300. Donchin further asserts:

> ...that for any given level of task relevance, if stimulus probability is varied, the amplitude of the P300 will also vary. The rarer the stimulus, the larger the P300 (15:506).

Task relevance may help to explain why a peak appears in the P300 latency range for both critical and non-critical events in Wilson's data. In the process of distinguishing critical and non-critical events, both events are task relevant. To eliminate it as a source of amplitude variation, event probability is kept constant for all the experimental conditions in this study.

P300 Latency

If the P300 has a consistent temporal connection to a cognitive decision, then its latency should correlate with independent behavioral measures known to reflect the latency of the decision. The evidence for such a correlation is not conclusive. The most common behavioral measure of decision latency is motor reaction time. Some researchers have observed reaction time variation parallel P300 latency. But others found the correlation to be less positive and a number of experiments demonstrated a dissociation between P300 latency and reaction time (16:166).

For example, one experimenter manipulated the ease with which the stimulus can be discriminated. The supposed effect was to vary the subject´s degree of certainty after the event that he or she perceived it correctly. This lack of confidence in the decision is sometimes referred to as a posteriori uncertainty or equivocation. Data show both P300 latency and reaction time increase with greater equivocation. But the magnitude of change in reaction time is 3-5 times greater than that of the P300 latency (16:166). Ford and Koppell varied the frequency (pitch) difference between two tones that were to be discriminated. As the frequency difference decreased (increasing equivocation), the average reaction time increased by 81 ms while the P300 latency only increased by 26 ms (17:32-39). Roth also used tone frequencies and reported a reaction time increase of 180 ms with a P300 lltency increase of only 31 ms. He suggested that the dissociation may be more apparent when task instructions emphasize speed above accuracy of response (14:22).

A vigilance task requires the subject to monitor for the occurence of a specified stimulus and respond in some prescribed manner upon detecting that stimulus. Parasuraman and Davies found that both P300 latency and reaction time were longer for false alarms than for hits in a visual vigilance task. Again, the magnitude of difference in reaction time was greater than the

difference in P300 latency (18:465-468).

In a number of memory load experiments, both the reaction time and the P300 latency increased linearly as a function of the number of memory items. Reaction time became asymptotic at Miller´s number of seven items. Furthermore, in each experiment, the slope of the reaction time increase was steeper than the slope of the P300 latency increase (7:530-531).

In other experiments, the stimulus discriminability was maintained at a high level while the stimulus probability was lowered. As the probability of the event decreased, the reaction time increased considerably, but the P300 latency remained constant or decreased slightly (19:188-196) (20:71-75). Under certain circumstances, the peak of the parietal-occipital P300 for a particular trial appears after the subject´s reaction in that trial (21:283-289). This argues against any causal correlation between P300 latency and reaction time. There may be some sort of indirect relationship between P300 latency and reaction time but there is little to support the conclusion of a direct relationship between the two (16:166).

A negative peak with a latency of about 190 ms has emerged from principal component analysis of data from several experiments. This N190 (or N2) component is smaller and often masked by the P300. It is like the P300 in that it has the same range of latency variation and it

increases in size as stimulus probability decreases. Unlike the P300, it is modality specific and it may be more directly related to decision latency. The N190 is rarely observed apart from certain experimental paradigms which separate it from the P300. More research is needed to discover its characteristics (16:161,167,169).

The prevaling interpretation is that P300 latency is not related to response selection or execution but to stimulus evaluation time. This would account for its increase when low probability or less discriminable stimuli are encountered. Donchin conducted an experiment using two manipulations known to increase reaction time: stimulus noise and response incompatability. The addition of noise to the stimulus slows reaction time because stimulus encoding and evaluation require more time. Response incompatability slows reaction time by interfering with response selection and execution. Data confirmed that, whereas both manipulations increased reaction time, only the addition of noise increased P300 latency. In promoting P300 latency as a dependent variable for studies of human information processing, Donchin makes the following optimistic assertion:

> The latency allows us to address a range of problems in cognitive psychology that require for their effective solution, a measure of mental timing uncontaminated by response selection and execution processes" (15:501).

The P300 and Motor Response

The P300 is not dependent on motor activity. One experiment, where larger P300s were elicited by low-probability responses as well as low-probability stimuli, suggests that P300 and behavioral response may be related in some manner (22:129-136). Motor-related potentials are eratic, high-frequency patterns which may occur briefly at the initiation of a moter response and can sometimes overlap the P300. But prominant P300 components are consistently found in the absence of any motor activity. Large P300s appear, for example, when the subject is tasked to count the number of rare stimuli and report the total later. And when motor activity is a requirement, most of the P300 component seems to follow the motor-related potentials chronologically (7:527). Consequently, the problem with motor-related potentials is not that they are functionally related to the P300, but that some may overlap the latency range of the P300 (especially at the central and parietal electrode sites where the P300 is apt to be measured). Tueting describes the three characteristic features of the motor-potential waveform:

(1) A slow premotor negative potential.
(2) A higher frequency complex associated more directly with response initiation.
(3) A large, slow postresponse positive wave peaking about 150 ms after response (thought by some to be related to somatosensory feedback from muscle and joint receptors) (16:164).

P300 and Arousal

An early controversy sought to determine whether the P300 reflects a specific, selective process following relevant stimuli or merely the dissipation of some non-specific state of arousal or alertness leading up to stimulus presentation. Some of the early methodologies were open to the possibility that interstimulus interval could be anticipated by the subjects. The P300 was thought be the brain´s transition to a less aroused state, since the subject was pretty sure another stimulus would not follow immediately. Numerous studies established the contingent negative variation (CNV) measure as a reliable index of arousal. A number of experiments used factorial experimental design and scalp location to demonstrate that the P300 varies independently of the CNV (7:510-511).

The P300 is often observed under the same conditions that invoke a slow, negative-going CNV expectancy process prior to the stimulus. This CNV process may confound accurate measurement and interpretation of the P300 waveform, because it frequently resolves into a slow,

positive-going, post-stimulus waveform in the latency region of the P300. The two can look very similar (16:165). The concern in the critical event detection task is that if the critical event is always presented as the final event in a block followed by a rest period, then the resolution of a state of arousal may confound the specific information processing components of the waveform.

P300 and the Orienting Response

Orienting response is the title given to a group of physiological changes elicited under conditions of novelty and uncertainty. Included are heart rate deceleration, pupillary dilation, galvanic skin response, and EEG desynchronization (23:178). All are measured responses of the human organism when it encounters new or low-probability stimuli in the environment. In 1968 Ritter observed that P300s were elicited under conditions identical to those which elicit the orienting response (24:550-556). But unlike components of the orienting response, P300 amplitudes do not habituate (decrease with many repeated trials) as long as the low-probability stimuli invoking them are intermixed with the high-probability stimuli. Massed low-probability stimuli do show a decrease in P300 amplitude, but that may be the subjects appraisal of its high probability for the short

term. Generally, the P300 does not habituate in the same manner as the orienting response though it does seem similar in other respects (7:512).

Multiple Late Positive Components

In 1973 Roth reported that infrequent, task-irrelevant trials produced reliable P300s. Up to that time, the common key in P300 research had been task-relevance. But Roth also reported that the P300s were observed much earlier (mean latency of 210 ms) than the P300s observed in other experiments (25:125-137). One possible explanation was that there are really two P300s. One is elicited by the same factors that elicit the orienting response. The other is elicited by task-relevant stimuli (23:179). Tueting cautions against using latency alone to seperate P300 components and identifies the following criteria for isolating P300 subcomponents:

(1) Waveform characteristics (amplitude and latency).
(2) Scalp distribution (usually merely defining midline maximum) (16:162).

One of the major ERP research trends has been the use of such criteria to observe and define multiple components of the P300.

Using auditory stimuli while subjects were engaged in another task (like reading), Squires found three distinct components of the P300 which he referred to as the late positive complex:

(1) A positive peak in the 220-280 ms latency range with a predominantly fronto-central distribution which is sensitive to changes in stimulus probability(sometimes referred to as the P3a).

(2) A positive peak in the 310-380 ms latency range with a parietal maximum which depends on task-relevance of the stimulus (sometimes referred to as the P3b).

(3) A later slow wave which is positive at the parietal midline electrode and negative at the frontal electrode (sometimes referred to as slow wave or SW) (26:381).

Using a variety of auditory decision tasks Hillyard reported (1) an early latency, small amplitude P3a with a fronto-central scalp distribution and (2) a later, larger, centro-parietally distributed P3b elicited by low-probability signals in a vigilance task (27:81-87). In addition, Courchesne reported a frontal P300 elicited by novel, visual stimuli that were not task-relevant. Two unusual features of this component were its long latency and its rapid habituation as the novelty of the stimulus

decreased (28:131-143). The visual frontal P300 and the auditory P3a are most frequently associated with orienting behavior for the following reasons:

(1) Subjects orient to low-probability stimuli even when instructed to ignore them and even when attending stimuli related to a separate concurrent task.

(2) Frontal component amplitude increases with the complexity/non-recognizability of the stimulus.

(3) The frontal component habituates rapidly as the stimulus loses its novelty (16:162-163).

Friedman makes the interesting observation that orienting is reduced or absent in patients with frontal lobe damage (29) (16:162-163). But the relevance of such an observation depends on some tenuous assumptions regarding scalp distribution (to be discussed later).

The P3b (parietal P300) seems to be a more cognitive component which may indicate the processing of task-relevance or decision-related information. It is commonly elicited by low-probability target stimuli related to a specific task. It is considered cognitive because it can be elicited by the absence of a stimulus when the absence is task-relevant. For example, Simson observed a "positive missing stimulus potential" when stimulus omissions from a continuous series are rare and task-related (30:33-42). In addition, the latency of the

P3b peak varies from trial to trial within a subject suggesting an internal trigger (16:163).

Chapman used a complex information processing task which involved the serial presentation of four visual stimuli in random sequence. Two of them were single-digit numbers. Two of them were single letters. The four were sandwiched between two blank flashes in an attempt to reduce first-stimulus effects. One condition required the subjects to indicate, by moving a lever left or right, whether the first or second number was higher in magnitude. The other condition required the subjects to indicate whether the first or second letter was later in the alphabet. This paradigm allowed separate observation of: (1) stimuli which are not response-relevant, (2) stimuli which require information storage, and (3) stimuli which require information comparison, decision and response. Principal components analysis identified 8 independent factors seemed to support the multiple P300 theory. Factor #2 appeared as a positive, parietal component half up at 260 ms and maximum at 410 ms after the stimulus. It was highly sensitive to the main effect of stimulus relevance and its variation was very similar to the mean amplitude of the P300. The similarity was due to its prominence, late positivity, and high percentage of contribution to total variance. Factor #1 behaved like the CNV waveform. It was negative at the time of the stimulus and slowly moved up to the baseline as the CNV

resolved after the stimulus. Factor #3 appeared as a positive peak at about 250 ms and seemed to relate to information storage. Factors #5 and #8 were present only when letters were evaluated, not numbers. Factors #4, #6, and #7 were difficult to interpret (31:94-99).

Roth asserts that of the three variables used to define EP components (time,voltage, and scalp location), scalp location has become the most favored. Spatial distributions are typically expressed by comparing the relative amplitudes of the same P300 measured at 3 or 4 locations anterior-to-posterior along the midline of the scalp. For example, Fz=Cz<Pz>Oz indicates a predominantly parietal distribution in which the amplitude at the frontal, central, and occipital locations are approximately equal and less than the parietal. Roth´s summary of multiple P300 research contains the following possible components:

(1) A P3a with a latency which can overlap the P2 component or be out as long as 300 ms. It is elicited by rare, task-irrelevant stimuli.

(2) A P3b, representing much of what was formerly known as the standard P300, with a latency of 300 to 400 ms.

(3) Components in the 400+ ms range. Picton observed what he termed a P4 component with a definite peak at 650 ms. It appeared for

auditory stimuli which gave feedback as to the correctness of choices made in a visual concept learning task. The peak was only apparent during the learning stages. It did not appear after mastery of the task (32:519). In a different experiment, Courchesne elicited a positive peak at 417 ms for rare, task-relevant targets and 448 ms for equally rare, but non-target stimuli (33:589-592).

(4) A slow wave appears for task-relevant stimuli beginning after 300 ms and lasting for more than 1 second with a scalp distribution distinct from the CNV (34:170).

Roth then summarizes the 4 anterior-to-posterior, midline scalp distributions that describe these waves:

> (1) A predominantly parietal-central distribution (Fz<Cz<Pz>>Oz) is characteristic of most peaks in the P3b latency range and missing stimulus potentials. (2) A predominantly frontal-central distribution (Fz=Cz>Pz>Oz) is said to be characteristic of the P3a component... (3) A parietal-occipital distribution (Fz<Cz<Pz=Oz) was found for "P4". (4) A distribution in which the polarity differs by lead was found for the slow wave. This wave is positive at Pz, almost absent at Cz, and negative at Fz (34:170).

Roth offers some important cautions. Differences in amplitude, latency and topography do not necessarily

indicate different processes. Topograghy, for example, assumes spatially distinct generators and pathways in the brain. But brain pathways are not well-understood and may not be well-represented by EPs. In the case of Picton´s P4 after an earlier P3, the two components differ in latency and scalp distribution. But that does not prove they represent separate processes. In fact, the two are affected identically by the experimental variables. Picton´s conclusion that one represents appreciation of feedback (P3) and the other, use of it in learning seem to hang on insufficient evidence. As far as it is possible, the experimental conditions should identify separate processes to confirm or disconfirm such differences in latency and scalp distribution. Roth concludes, "In general, the case for multiple LPW }late positive wave^ processes is unproven. More data are needed, particularly on the experimental parameters that affect late wave distribution" (34:172). But more experiments designed like Chapman´s may yet confirm multiple P300s.

Functional Postulates of the P300

Inspite of assumptions, limitations, lack of standards and other difficulties associated with eliciting, measuring, extracting and interpreting the P300 waveform, many researchers have added yet another assumption by seeking a unified explanation of its

functional significance. Postulates for a functional P300 construct have included uncertainty, information delivery, salience, significance, incentive value, orienting, inhibition, selective recognition, and awareness. Even amidst the shift toward multiple P300 components, Donchin has proposed that the P300 represents a single, dedicated process required and called like a subroutine by a variety of tasks. The variety of tasks which elicit the P300 include guessing, feedback, detection, among other forms of information processing. One underlying feature in each of these tasks is a match/mismatch judgement which may be comparing the stimulus with some representation of it in memory (16:161-167).

Some researchers have suggested that the P300 is the result of a match between the sensory encoding of a stimulus and an internal neural representation or template of the stimulus (7:517). In support of this, Thatcher demonstrated that a P300 could be invoked independent of probability using a sequential matching task. The P300 observed when the second letter matched the first letter was higher than when the second letter was a mismatch regardless of probability (35:429-448). Posner also asserted that the P300 indicates a matching process because it appeared earlier for a match judgement than for a mismatch judgement (36:2-12). But several experiments have shown that matches can produce smaller and longer-latency P300s when stimulus probability is varied.

The idea that an internal template involves a matching of physical parameters cannot be attributed to the late P300 waveform. If the template is defined by physical parameters, then the P300 is too independent of the physical properties of stimuli and too closely tied to the task context to reflect such a stimulus template-matching process. Additionally, Pritchard states that "the latency of the P300 strongly indicates that it is a postidentification phenomenon, based in part on a matching process, but not a real-time reflection" of it (7:518).

Others have postulated that the P300 represents additional perceptual cognitive processes called upon to evaluate the significance of an orienting response precipitated by a mismatch (37:326-328) (16:167). But Donchin suggests that the P300 has little to do with information processing for the immediate decision or response. He asserts, instead, that the P300 reflects the process of updating a "strategic" neuronal model of all aspects of the situation for the purpose of evaluating strategy changes, expectancies, etc. Its purpose is to apply information gleaned from the eliciting event to update this internal scheme of the environment in preparation for future events. In other words, the P300 will be elicited to the degree that the stimulus requires a revision of the "schema" stored in the "working memory."

This theory implies that events which elicit a P300 are more likely to be remembered than events which do not

invoke a P300 (15:507-510). Fabiani demonstrated that P300 is proportional to successful recall in a von Restorff (better recall of "isolated" items) experiment (38:5a). Klein compared the P300s elicited by auditory verses visual oddball paradigms in four control subjects and four subjects known to have absolute pitch. As expected, the P300s elicited for the control subjects showed no appreciable difference across modalities, but as Donchin´s theory predicted, subjects with absolute pitch produced auditory P300s with markedly lower amplitudes than the visual P300s. Presumably, the subjects with absolute pitch are able to maintain a permanent internal representation of the pitch requiring less revision (39:8). Donchin´s view is consistant with the effects of probability, task-relevance, learning and mismatch on P300 amplitude, the stimulus evaluation time view of its latency, P300 appearance for stimulus omission, and the its independence of the response decision to the point of appearing after the response is initiated.

III DUAL TASK P300 RESEARCH

Observations of subjects presented with two concurrent tasks indicate that P300 amplitude may be sensitive to variations in cognitive and perceptual workload. Researchers have formulated two theoretical models to account for the brain´s division of attention between two tasks. Capacity theorists conceive of mental attention as a single undifferentiated reservoir which the brain allocates in continuous modulated quantities to tasks as required. According to this theory, manipulation of one task will have an inverse and proportional affect on the amount of resources available for other concurrent tasks. When applied literally, this model does not account for a number of results reported in the literature (3:240). For example, difficulty manipulations of one task can leave performance of the other concurrent task unaffected (40:401-412). Structural theorists, on the other hand, relate attention to the competition among tasks for discreet information processing mechanisms (or structures) necessary to perform them. Wickens describes a third model which contains both capacity and structural elements. According to this theory, specialized structures can allocate their processing resources in continuous quantities between concurrent activities, but each structure has a set limit of total resources. In

other words, attentional resources are shared across tasks but not across certain dedicated structural divisions or pools representing specific information processing functions (3:239-241). The design of the dual task conditions in this experiment assumes mental resources are allocated according to the third model. In this context, a resource is no more than a hypothetical construct which accounts for variance in performance. Resources refer to supposed instruments which are inherent to the human processing system and are used to perform the task (41:1).

Wickens, Donchin, Israel, and Kramer have conducted experiments to assess the utility of the P300 as a measure of the mental resources consumed by a task (workload). In one experiment, the subjects were given two concurrent tasks. They were instructed to give first priority to the task of tracking a moving object. Hence, tracking was the primary task. The secondary task was to count the less frequent tones in an auditory oddball presentation. P300 amplitudes from the infrequent, counted tones were subtantially lowered by the introduction of the tracking task. But once tracking was introduced, the same amplitudes were unaffected by increases in difficulty of the tracking task (as indicated by an increase in reaction time and error count associated with the tones). Follow-up experiments indicated that P300 amplitude is specifically sensitive to variation in perceptual load. If the difficulty of a perceptually demanding primary task

was increased, the P300 amplitudes from infrequent tones decreased. On the other hand, increasing the difficulty of a primary task which placed heavy demands on manual responses had only a small effect on P300 amplitude. The same results were obtained using visual oddball flashes and more complex primary tasks. These results led to the suggestion that P300 amplitude might be used as a dependent variable to analyze specific components of human workload (15:502-503).

Musso and Harter found that children with reading disabilities secondary to perceptual problems (but normal IQs) had larger than normal P300s for targets in a discrimination task though their behavioral performance was normal. Pritchard suggests that the children with reading disabilities had to allocate more than the normal amount of perceptual resources to accomplish the task and he concludes that P300 amplitude seems to index limited-capacity perceptual processing (7:529).

Wickens concludes that the larger the demands of the primary task, the smaller the P300 elicited by the secondary task as long as the demand loads perceptual or cognitive types of capacities. The assumption is that the secondary task P300 taps a pool of perceptual resources that must be shared with the primary task. Hence, the P300 may can serve as an index of specific resources still available to an operator occupied with the primary task. Furthermore, secondary task P300 amplitude would then

serve as an inverse index of primary task difficulty. In another experiment, Wickens observed that the diminuation of the P300 for the secondary task was accompanied by a reciprocal rise in the P300 elicited by the primary task as primary task difficulty increased. In other words, P300s for the concurrent tasks fluctuate in a reciprocal manner (42:3-7).

Wickens offers three possible means of organizing the structural composition of attentional resource reservoirs: (1) processing modalities, (2) cerebral hemisphere of operation, and (3) stages of processing. The sensory modalities of processing include visual vs. auditory encoding or manual vs. vocal responding. Cerebral hemisphere of operation refers to the predominant control over certain resources maintained by the right or left halves of the brain. Stages of processing refers to the serial functions performed on stimuli. First, the stimulus is perceptually encoded from sensory inputs. The information is then centrally processed. Finally, the appropriate response is made (3:242). This study investigates the three stages of processing while attempting to hold the cerebral hemisphere and sensory modality constant across conditions. The identification of serial processing stages does not, in itself, argue for independent resource pools. But evidence from dual task methodologies suggests that these stages do often draw from independent structures. For example, Shaffer

investigated the same three processing stages (encoding, central processing, and responding) and found that they can proceed concurrently with little mutual interference. Such results suggest that each stage relies on non-overlapping resource structures (43:107-112). Heffley and Donchin reported that the P300 did not index differing mental calculations performed on numbers in a math task (44:173) (7:534). Other dual task studies demonstrate that tasks which place demands on perceptual encoding can be efficiently time-shared with tasks which place demands on responding. Furthermore, varying the difficulty of a task which primarily loads one stage of processing generates little interference with tasks which primarily load a different stage (3:242-243).

Wickens identifies two dual task paradigms which may be used to investigate dedicated processing structures: (1) manipulation of the relative priority assigned to each task or (2) manipulation of the difficulty of either task (3:242). In the first paradigm, task difficulties remain constant while relative priorities are manipulated by instructing subjects to give higher, equal, or lower priority to one of the two concurrent tasks. In the second paradigm, relative priority remains constant while the difficulty of one of the two concurrent tasks is manipulated.

SUMMARY

Donchin provides a very succinct summary of P300 research:

> We know that events that are task relevant and rare elicit a large P300. The larger the probability, the smaller the P300. The more important the event, the larger the P300. If the series of events that elicit the P300 are embedded in a task that competes for the subject's attention with yet another task that places priority demand on stimulus evaluation processes, we are likely to observe a reduction in the amplitude of P300, suggesting a decrease of available resources (15:504).

IV Methodology

Critical Event Detection Task

The critical event detection task stimulus used in this experiment follows the same pattern used by Wilson, Hall, and Hann (6:3-4). It consists of seven binary digits. All seven are presented simultaneously and consecutively in a single, horizontal row. A typical stimulus might look like this:

1010011

The above stimulus represents a non-critical event because it does not contain four consecutive ´1´s. A critical event is indicated by the appearance of four consecutive ones anywhere in the seven-digit pattern. For example, the following stimulus indicates a critical event:

1011110

As a convenient means of managing stimulus probability and random presentation, the stimuli are organized by groups of five within the computer program written to generate the diplay. But the grouping of stimuli is transparent to the subject in every experimental condition except the partial replication.

The critical event detection task incorporates a rudimentary simulation of the buildup of a critical

command and control sequence. Hence, another characteristic of the critical event is its sequential relationship to the two non-critical events which precede it. The critical event does not appear without warning. It is always preceded by a non-critical event containing three consecutive ones which is, itself, preceded by a non-critical event containing two consecutive ones. The reverse is not necessarily true. For example, three consecutive ones are not always followed by a critical event. Thus, a typical group containing a critical event might look like this:

First stimulus:	0110011
Second stimulus:	1001100
Third stimulus:	0011101
Fourth stimulus:	0011110
Fifth stimulus:	1011100

The fourth stimulus indicates a critical event. The second and third stimuli contain two and three consecutive ones, respectively.

Friedman used an interstimulus interval (ISI) of 1.5 seconds, a stimulus duration of 50 ms, and a target-to-nontarget probability ratio of.20/.80 for his visual discrimination task (50:197). But because of the greater complexity of the critical event stimulus and its projected use in dual task paradigms, the average ISI is longer than Friedman's allowing more time to process the

stimulus. In addition, the stimulus is presented at random intervals. The random intervals preclude the "differential prestimulus states" which may occur when the subject is able to predict the onset of the stimulus (16:161). Consequently, the ISI, if defined as the time between onset of consecutive stimuli, varies randomly between 1.5 and 3.0 seconds. Since the duration of the stimulus is one of the independent variables under study, it ranges from 50 ms to about 1.5 seconds according to increments defined in the applicable experimental conditions.

The critical event occurs only once in each series of five events and it always occurs as the third, fourth, or fifth stimulus in the series. The other four trials in each group are non-critical events. Because the probability of a stimulus may differentially affect its late positive ERP components, the overall stimulus probabilities during this experiment are kept constant. Donchin and Wickens found that the sensitivity of the P300 amplitude to changes in the probability of a target stimulus relative to a nontarget stimulus is affected by the the length of the ISI. Using the oddball paradigm, they compared 3.0 second verses 1.3 second ISIs and .20/.80 verses .80/.20 target-to-nontarget probability ratios. At an ISI of 3 seconds, the P300 is always relatively larger for the target than for the nontarget. At an ISI of 1.3 seconds, the P300 for target stimuli

became relatively smaller as the targets became more probable (46:6). Since the ISI in this experiment nearly spans the range studied by Donchin and Wickens, the effect of probability is controlled by maintaining a constant target-to-nontarget stimulus probability ratio of .20/.80.

The broad definition given to a non-critical event in this experiment permits a great variety of unique nontarget stimuli. The question arises as to whether the target-to-nontarget probability ratio is to be based on nontargets as a class, specific nontargets, or some combination of both. Friedman found, however, that class probability and not the probability of a given non-target affects P300 amplitude. Furthermore, non-signal (or non-target) P300 amplitudes are negatively related to the frequency of the class comprizing the non-signals and are unrelated to the probability of any particular non-signal within that class (47:197).

The subject is instructed to watch a video display as the series of seven-digit stimuli are presented. If the trial indicates a critical event, the subject depresses a button-switch using the non-dominant hand. Pilot studies conducted by Wilson, Ward, and Hann had demonstrated similar results for either hand. Since the dominant hand is later used for other (primary) tasks during the dual task conditions, the non-dominant hand is exclussively assigned to the critical event detection response throughout the experiment. As a result, variations in

reaction time, response performance, and EEG waveform caused by switching hands are eliminated. Subjects are instructed to respond only after they are certain the stimulus indicates a critical event and then. If the subject determines that the stimulus does not indicate a critical event, no action is required. When the experimental condition requires the subject to perform dual tasks, the critical event task is secondary and is not initiated until after the subject is already involved in the primary task.

Tracking Task

The instability tracking task is part of the criterion task set developed and tested at the Air Force Aeromedical Research Laboratory (AFAMRL) as a standardized loading task. It is similar to the tracking task developed by Jex (48:138-145). Variable demands may be placed on operator processing required to perform manual responses by manipulating the amount of instability introduced into the controlled element. A fixed 1/8 inch by 3/32 inch rectangular target is centered on the video screen. A cursor identical to the target moves laterally from this same center position to the left or right edge of a four inch wide screen area. The subject attempts to keep the cursor centered over the target by making left and right inputs with a control stick. The system is

inherently unstable, however. The subject's input introduces error. The error is magnified by the system to the degree set by selecting a lambda level on the tracking equipment (see apparatus section for description). As a result, it becomes increasingly necessary to respond to the velocity of the cursor movement in addition to its position. When the cursor reaches the edge of the display (referred to as a control loss) it instantly resets to the center position and begins to move outward again. Thus, the subject is continually occupied attempting to keep the cursor centered.

The hardware implementation of instability tracking at AFAMRL measures subject performance by recording integrated tracking deviations and control losses. Based on these measures and subjective ratings on numerous test trials, three significantly different difficulty levels of tracking demand are represented. Low, moderate, and high demand levels are obtained by lambda settings of 2.1, 4.5, and 5.7, respectively. The two lambda levels representing easy and hard tracking in this experiment were set at 2.5 and 5.0, respectively.

Significant practice effects are reduced by giving the subject seven 3-minute training trials at each lambda level. The subjects are instructed to keep the cursor centered on the target as much as possible. They are further instructed to avoid allowing the cursor to move off the edge of the screen. Control is input using a

finger-operated, self-centering joystick. The subject begins the task at the instruction of the experimenter. When used in the dual task condition, the subject begins tracking prior to the onset of the first critical event detection stimulus and finishes tracking after completion of the last critical event detection stimulus.

Mental Math Task

The mental math task is a standardized loading task revised for use in this experiment from the mental math task in the criterion task set developed and tested at AFAMRL. It places variable demands on central processing resources used to manipulate and compare numeric information. The task requires the subject to perform one or more simple arithmetic operations on single digit numbers to determine if the answer is greater or less than a prespecified value.

Previous test runs indicate three significantly different task demand levels. The low level uses one-operator addition or subtraction problems like: 1+6. The moderate level uses two-operator problems with addition-subtraction (+-), subtraction-addition(-+), or subtraction-subtraction (--) combinations like: 6-5+2. The high demand level uses three-operator problems with ++-,+--, or -+- combinations like: 4+2+1-3. Mean reaction time, percent correct, and subjective task difficulty

ratings were used to validate these demand levels. Only the low and high demand levels are used in this experiment.

Practice is required to reduce the effect of training to nonsignificant levels. The amount of practice needed depends on the number of operators. The one operator condition requires about 20 minutes of practice. The three operator condition requires between 80 and 100 minutes of practice. Subjects were instructed to respond on the computer keyboard provided using their dominant hand. If the answer was greater than five, they were to depress the "greater than" key (>), If the answer was less than five, they were to depress the "less than" key (<). In order to maintain a more or less constant load, the next problem is presented as soon as a response is made to the current problem or three seconds after its onset, whichever occurs first.

Monitoring Task

The probability monitoring task is another standardized loading task revised for use in this experiment from the probability monitoring task in the criterion task set developed and tested at AFAMRL. It is based on a paradigm originally developed by Chiles, Alluisi, and Adams (49:143-196). In the task, subjects are required to monitor 1, 3, or 4 computer generated

displays which simulate the appearance of electro-mechanical dials. Each dial consists of a row of six verical hashmarks. A seventh hashmark just above the six indicates the center of the dial. A number at the left of each dial identifies it as dial number 1, 2, 3, or 4. Under normal (non-signal) conditions an arrow moves from one of the six hashmarks to another in a random fashion simulating random pointer fluctuations on a dial. At unpredictable intervals the pointer on one of the dials begins to move nonrandomly, staying predominantly among the left or right three hashmarks. These biases to the left or right three half of a dial are the targets or signals to which the subject is instructed to respond. Depression of the appropriate response key will reset the arrow movements to the random or nonsignal condition.

Three significantly different task demand levels have been tested. The low demand level was produced using 1 dial at a 92.5/7.5% bias level. The medium demand level used 3 dials at an 85/15% bias level. The high demand level used 4 dials at 75/25% bias level. Mean reaction times and mean subjective task difficulty ratings were used to validate the differences in loading. Two levels of demand are used in this experiment. The easy level uses 1 dial with a 92.5/7.5% bias level. The difficult level uses 3 dials with a bias level at 75/25%.

Extensive practice is not required. The subject is shown the different levels of bias and instructed to

respond only after they are certain that the signal is present. The subject is informed that only 2 to 4 signals will occur during the 3-minute trial period. Responses to signals are made using the number key (on the computer keyboard) which corresponds to the number at the left of the biasing dial. Performance measures include reaction time to correctly detected signals, number of responses when no signal is present (false positives) , and overlooked signals (misses).

Subjects

The experiment initially planned to record data from twelve subjects. Subjects ranged in age from 19 to 44 with an average age of 23.5 years. The seven males and five females had all been subjects for psychophysiological and human factors experiments in the past. All of them were trained in advance on the tasks required in this experiment. One of the twelve had also been a subject for the Wilson, Ward, and Hann experiment. Following the experiment, subjects were asked to complete a questionnaire soliciting backround information, subjective ratings of task difficulties, strategies they used to accomplish the dual tasks, and any other impressions.

Experimental Design

The experiment obtains repeated measures of all variables for each of the subjects. The design actually incorporates five experiments or principal areas of investigation. Thirteen experimental conditions (numbered from 0 to 12) are used in the investigation. To the extent that the experimental conditions make the ERP components vary independently, rendering nonidentical waveforms over their entire time course, the underlying components can be identified and measured by varimaxed rotation principal components analysis (31:97). The repeated measures may then be subjected to analysis of variance to determine the significance of the relationship between experimental condition and the component of interest. The principal areas of investigation and experimental conditions follow.

Experiment A. Experiment A is both a partial replication of Wilson, Ward, and Hahn's experiment (condition 0) and a comparison of it with an experimental condition which does not include rest periods after each critical event (condition 1). In Wilson, Ward, and Hahn's experiment, the critical event always indicated the end of a block and the beginning of a short rest period prior to the next block of events. Such a manner of presentation opens the door to a more pronounced relaxation of alertness. The confounding effect of the stronger,

post-stimulus CNV resolution might make the critical event waveform appear more positive than the non-critical event waveform. The effect would not have been detected in the principal components analysis because all conditions were presented in the same manner. The independant variable is the temporal relationship of the critical event to the event which follows it. The dependent variables are ERP component latency, ERP component amplitude, and reaction time. In the remaining four areas of investigation, all conditions do away with the rest periods.

Experiment B. Experiment B compares the waveforms elicited by increasingly long stimulus durations. In laboratory studies which use the transient EP, the experimental design usually imposes strict control over what the subject does and when he does it (31:83). While this is an asset in controlled research, it severely limits the use of transient EPs in operational environments. Cooper with others attempted to extend the use of transient ERPs to more long-term displays in a detection task. They found a large positive component with a central-parietal midline maximum which followed the last eye movement to the target by 200 to 300 ms (50:192-193). In this experiment, five experimental conditions (conditions 1-5) vary the duration of the stimulus to investigate if and when critical event detection can no longer be observed in the transient ERP waveform. The longest duration continues to display each

stimulus until onset of the next stimulus in an effort to simulate real-world-like digital displays. The independent variable for this experiment is stimulus duration. The dependent variables are ERP component latency, ERP component amplitude, and reaction time.

Experiment C. Experiment C compares the waveform elicited by the reaction time task to the waveform elicited by a task which does not require a motor response. One of the problems encountered in trying to relate long-latency positive ERP components to information processing when the task involves a motor response is the interfere of psychomotor potentials. The technique used in this experiment to examine the difference in the waveform contributed by psychomotor potentials is called a delayed-response task. For the delayed-response task (condition 12), the subject keeps a tally of the number of critical events which occur and reports the cumulative total after the entire condition has been presented. In this manner, the psychomotor potentials following each critical event are omitted, and the resulting waveform is compared to the waveform elicited in the motor response task condition (condition 2). Some researchers note that delaying or omitting motor responses is likely to change the nature of the decision and other cognitive features of the task. Nevertheless, a delayed-response task is better than a no-task control condition (16:165). The independent variable is task definition. The dependent

variables are ERP component latency and amplitude.

Experiment D. Experiment D is not so much an experiment as it is the additional data collection required to obtain the spatial distribution for the ERP components of interest to the study. The midline scalp topograph of the ERP components has become an important input to their classification and use. For this area of investigation, ERP measurements are taken from three midline electrode locations: the parietal, the central, and the frontal. Equipment limitation on the number of recording channels available did not allow an electrode at the occipital site. Dependent variables are ERP component latency and amplitude at each of the three scalp locations.

Experiment E. Experiment E compares the waveform elicited by the event (containing three consecutive ones) which immediately precedes the critical event with the waveform elicited by the critical event and the waveform elicited by other non-critical events. K. Squires with others investigated different sequences of frequent backround stimuli leading up to random rare target stimuli. Their results suggested that a stimulus elicits a larger P300 if preceded by more of the same than if preceded by different stimuli (16:168). The critical event sequence simulates a sequence of command and control indications where a critical state is always preceded by a build up, but a build is not always followed by a critical

state. The hypothesis is that evidence that the subject recognizes the event which precedes the critical event will appear in the ERP. The independant variable is sequential position/type of stimulus. The dependent variables are ERP component latencies, ERP component amplitudes, and reaction times.

Experiment F. For the conditions in experiment F (conditions 5-11), critical event detection is the secondary task. Students are instructed to give priority to a concurrent primary task rather than the critical event task. Experiment F compares ERP latencies and amplitudes from the critical event task across two difficulty levels for each primary task. Each of three primary tasks loads a different processing stage. Probability monitoring loads perceptual encoding resources. Mental math loads central processing resources. Tracking loads manual response resources.

Friedman may be the only researcher aside from Wilson, Ward, and Hahn to report two late positive components from a vigilance/detection type of task. He observed both a P341 (which he found to be similar to a P3b) and a P539 which correlated closely with reaction time. Friedman's stimuli were two-digit numbers (02-19). He employed two tasks. In one, the target was the number, 08. In the other, the target was any repeat of the same number. The signal-to-nonsignal ration was 1:4. The stimulus duration was 50 ms with an ISI of 1.5 seconds.

The display width subtended a visual angle of 2 degrees and 20 minutes. Friedman suggested that it was unclear whether the P539 represented central processing, discrimination, response selection, or some other cognitive activity (50:321-322). The variation of primary tasks in this experiment may provide clues to the cognitive activity indicated by the P525.

Two additional functions are served by observing the effect of these loads on the late positive components of the critical event task: (1) preliminary assessment of the critical event task as a workload metric and (2) comparison of the P525 to the P300 to see if they respond independently to the experimental manipulations. The independent variables are type of primary task and level of demand within each primary task. Dependent variables are ERP component latencies, ERP component amplitudes, and reaction times.

Conditions

The following thirteen conditions are used to collect measurements of the independent variables for the five experiments. Three of the conditions (6a, 8a, and 10a) provide baseline primary task performance measures to assess the obtrusiveness of the secondary critical event detection task.

Condition 0. The grouped-event condition replicates

part of Wilson, Ward, and Hann's experiment in an attempt to reproduce the same ERP components. As in other conditions, the critical event may occur on the third, fourth, or fifth stimulus in the group. When the critical event stimulus occurs, it always ends the series. Immediately after the critical event a brief rest period (about eight seconds) precedes the first trial of the next group. Groups consist of three, four, or five stimulus events depending on which stimulus contains the critical event. The average number of stimuli in a group is four. In addition, three groups of five stimuli which contain no critical events are included among the 15 other groups. As a result, there are 75 events in all: 15 critical events and 75 non-critical events. The overall probability of a critical event is .20. Stimulus duration is 50 ms. ISI is random between approximately 1.5 and 3 seconds. The time required for a subject to complete this condition is about 6 minutes.

Condition 1. The 50 ms stimulus condition presents the stimuli in one continuous series containing 15 critical events and 60 non-critical. The stimuli are organized in groups of five, but the groups are not apparent because the same ISI links the fifth stimulus in each group to the first stimulus in the next group. All groups contain five events. The critical event occurs on the third, fourth, or fifth stimulus in each group. The series of five stimuli in a group does not end when a

critical event occurs, there is no rest period between groups, and the three groups with no critical event are eliminated. In other words, the subject sees one long series of 75 trials spaced from about 1.5 to three seconds apart. Fifteen of the trials are critical events. The stimulus duration is 50 ms. Time required to run this condition and each of the remaining conditions is about 3 minutes. Each of the remaining conditions uses the same continuous series of events except the order of the groups are randomized.

<u>Condition 2</u>. This condition is the same as condition 1 except a 150 ms stimulus duration is used.

<u>Condition 3</u>. This condition is the same as condition 2 except a 1 sec stimulus duration is used.

<u>Condition 4</u>. This condition is the same as condition 2 except a random 1.3 to 2.8 sec stimulus duration is used. In other words, each stimulus is removed from the screen 150 ms prior to the onset of the next stimulus.

<u>Condition 5</u>. This condition is the same as condition 2 except a random 1.45 to 2.95 sec stimulus duration is used. In other words, the stimulus remains on the screen until the onset of the next stimulus.

<u>Condition 6</u>. The low-demand tracking and critical event condition presents both tasks simultaneously. The primary task is low-demand tracking using a lambda level of 2.5. Critical event detection is the secondary task using the same parameters as in condition 2. The subject

is instructed to accomplish the tracking responses with his or her dominant hand and the critical event responses with the non-dominant hand.

Condition 6a. The subject performs low-demand tracking only without the secondary critical event detection task. The performance scores obtained from this condition are compared to the tracking performance scores from condition 6 to determine the effect of the secondary task on the performance of the primary task.

Condition 7. The high-demand tracking and critical event condition is the same as condition 6 except a high-demand tracking lambda of 5.0 is used.

Condition 7a The subject performs high-demand tracking only without the secondary critical event detection task. The performance scores obtained from this condition are compared to the tracking performance scores from condition 7 to determine the effect of the secondary task on the performance of the primary task.

Condition 8. The low-demand mental math and critical event condition presents both tasks simultaneously. The primary task is low-demand mental math using one operator addition or subtraction problems. Critical event detection is the secondary task using the same parameters as in condition 2. The subject is instructed to accomplish the primary task responses with his or her dominant hand and the critical event responses with the non-dominant hand.

Condition 8a. The subject performs low-demand mental math only without the secondary critical event detection task. The performance scores obtained from this condition are compared to the mental math performance scores from condition 8 to determine the effect of the secondary task on the performance of the primary task.

Condition 9. The high-demand mental math and critical event condition is the same as condition 8 except high-demand three operator addition and subtraction are used in the primary task.

Condition 9a. The subject performs high-demand mental math only without the secondary critical event detection task. The performance scores obtained from this condition are compared to the mental math performance scores from condition 9 to determine the effect of the secondary task on the performance of the primary task.

Condition 10. The low-demand probability monitoring and critical event condition presents both tasks simultaneously. The primary task is low-demand probability monitoring using one dial at the 95/5% bias level. Critical event detection is the secondary task using the same parameters as in condition 2. The subject is instructed to accomplish the primary task responses with his or her dominant hand and the critical event responses with the non-dominant hand.

Condition 10a. The subject performs low-demand probability monitoring only without the secondary critical

event detection task. The performance scores obtained from this condition are compared to the probability monitoring performance scores from condition 10 to determine the effect of the secondary task on the performance of the primary task.

Condition 11. The high-demand probability monitoring and critical event condition is the same as condition 10 except the high-demand level imposed by three dials at 75/25% bias are used in the primary task.

Conditon 12. The non-motor response condition differs from Condition 2 only by the response required of the subjects. The subjects do not depress a switch upon detection of the critical event. Instead, the subject is instructed to count the number of critical events and report the total following the presentation.

V APPARATUS

Throughout the experiment the subjects sit in a darkened acoustical enclosure in front of a table supporting the various behavioral response devices (computer keyboard, response button, and joystick). At about eye-level above and behind the table is a 15 X 15 centimeter (cm) square viewing window. Fig 3 shows a top view of the display configuration. Just outside the window, a glass pane is mounted at a 45 degree angle to the subject's line of sight. The side of the pane facing the subject is mirrored to reflect the image from a side video monitor. The other side of the pane is transparent glass which allows the image from the back video monitor to pass through. In this manner, the images from both side and back video monitors may be overlapped for the dual task conditions.

Critical Event Detection Task

The stimulus for the critical event detection task is generated by a Commodore 64 computer, displayed on a SC Electronics 12-inch video monitor, and reflected off the mirrored side of the diagonal glass. Custom characters are programmmed to eliminate the backward appearance of the '1's and to make the character sizes of the displays compatable. The characters are approximately .5 cm in

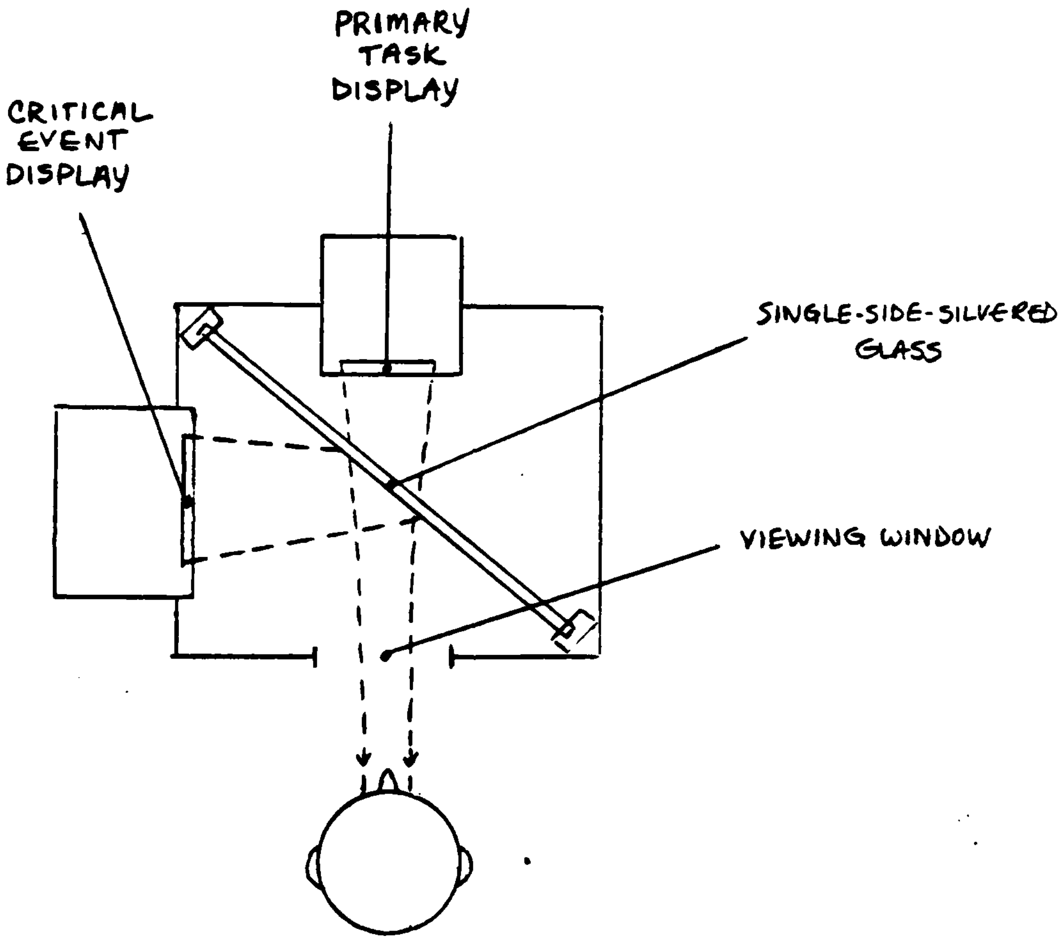


Fig 3. Display Configuration

height and .3 cm wide. The seven digits occupy 3 cm of display width. The total distance from the eyes of the subject to the display screen is about 112 cm. Hence, the horizontal visual angle produced by the width of the stimulus is approximately 1.5 degrees. The time from initial presentation of one stimulus to initial presentation of the next stimulus (ISI) is random from about 1.5 to 3 seconds. The duration of the stimulus is 156 ms for most experimental conditions and varied as an independent variable for the other conditions. Between events a small dot appears which is centered in the critical event display region to provide a visual fixation point.

The accuracy of the transient EEG averages depend to a large extent on the accuracy of the time-lock between stimulus onset and onset of the time-window to be averaged. Methods used to insure precise accuracy in previous psyhophysiological experiments at AFAMRL had not been satisfactory.

Since the stimulus is displayed on a video monitor, the actual onset of the screen display sent from the computer could be delayed as much as 16.67 ms depending on the relative screen location of the stimulus and the current raster scan. This amount of phase jitter is unacceptable. To reduce it, a machine language routine reads the computer's raster register until it contains a certain constant value. It then measures absolute and

precise intervals to generation of the trigger pulse for the EEG averager and display of the stimulus. The trigger pulse is sent to the EEG averager 156 ms prior to onset of the stimulus to provide a prestimulus baseline EEG measurement. Fig 4 diagrams the critical event detection task and EEG measurement setup.

The program generates trigger pulses on three different output lines depending on the type of stimulus. One output channel carries only the trigger pulses for the 195 critical event stimuli (15 in each of 13 experimental conditions). A second output channel carries 195 trigger pulses for the events containing three consecutive ´1´s which immediately precede each critical event. A third output channel carries 195 trigger pulses for events which are not critical events, do not contain three consecutive ´1´s, and do not immediately precede the critical event. Program listings for the critical event detection tasks are shown in Appendix A.

Tueting advises that the smaller the force and distance of the motor response, the smaller the interference of motor potentials in the average evoked potential (16:165). As a result, the response button for critical events is a soft-touch, minimum-travel microswitch. A machine language routine monitors whether or not the subject depresses the microswitch within 1 second after onset of the stimulus. If a response is made during that time, and the stimulus is not a critical

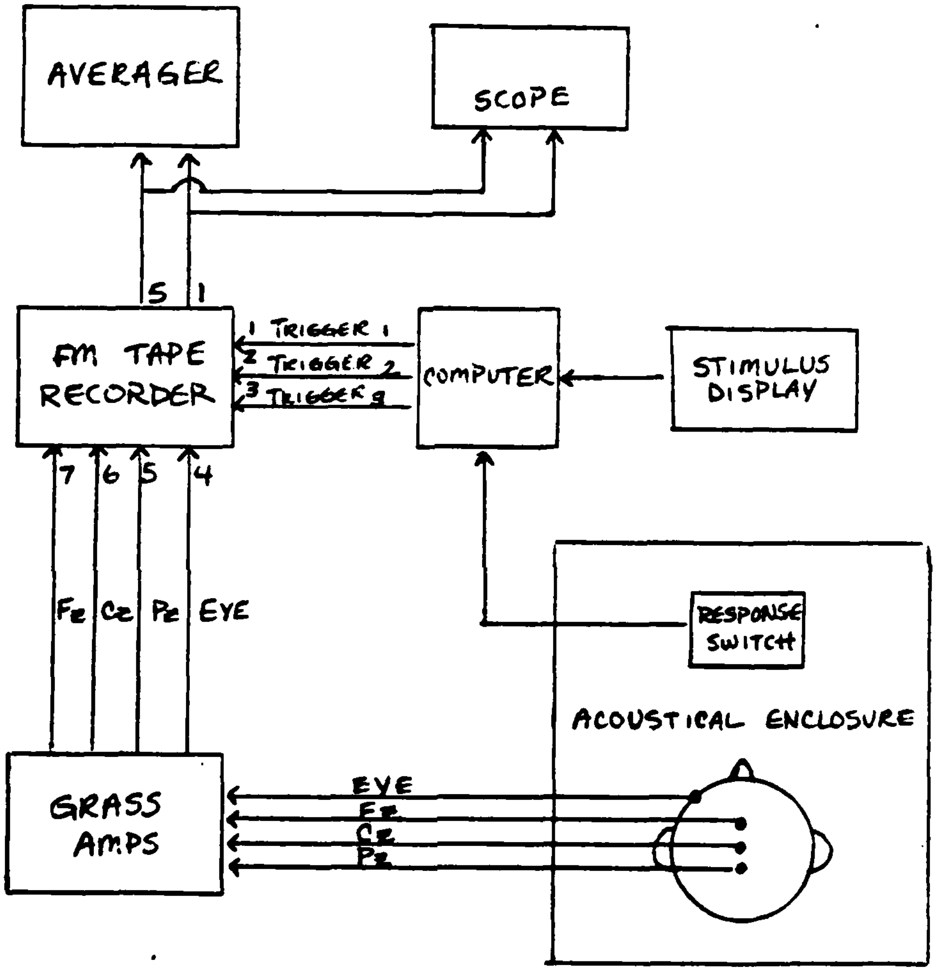


Fig 4. Critical Event Task and EEG Recording Setup

event, then the tally of false positives (false alarms) is incremented by one. If a response is made during the one second period, and the stimulus is a critical event, then the reaction time is recorded and rounded to millisecond accuracy. Misses are calculated by subtracting the number of hits from 15. After each experimental condition the reaction times for each critical event, the number of true positives (correct responses), mean reaction time, standard deviation, and number of false positives are stored in an array identified by the condition number. After the subject completes all conditions the array is labeled and stored on magnetic disk using a COMMODORE 1541 disk drive.

EEG Recording

Measurements for the transient evoked response are recorded using silver/silver chloride electrodes at the parietal (Pz), central (Cz), and frontal (Fz) midline scalp locations with one mastoid as reference and the other mastoid as ground. Locations were determined using the 10-20 International System (see Fig 2). Distances over the midline of the scalp are measured relative to the distance from the nasion (bridge of the nose) to the inion (bump at the base of the back of the skull). Pz is 30% up from the inion; Fz is 30% up from the nasion;and Cz is 50% up from either. Eye movements are also recorded on a

fourth EEG channel. Ideally an occipital (Oz) electrode is helpful for visual stimuli. But the recorder is limited to 7 channels and three are already used for trigger pulses. Since the components under investigation have long-latencies and the scope of the study encompasses the cognitive domain, the Oz location seemed to be less important to the establishment of a spatial distribution. A .5 to 1 cm diameter circle on the scalp is prepared for each EEG electrode by removing any hair, cleaning, lightly abrading, and applying a small amount of electrode cream. Resistance between the electrodes is kept below 5 K ohms.

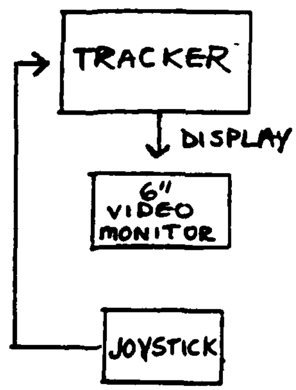
The EEG signals are amplified by a factor of 50,000 using Grass P511 AC amplifiers with a bandpass of .1 to 300 Hz. 60 Hz filters are also used to filter the ubiquitous interference from 60 Hz devices. No other filtering is applied. All trigger pulses and EEG channels are recorded for later reduction and analysis on magnetic tape with a Honeywell Model 5600B FM Tape Recorder. In addition, an on-line average of the Pz EEG using the critical event trigger checks proper operation of the equipment while data collection is in progress. Averages of 1024 time points in 800 ms epochs are accomplished using the Nicolet 660A Dual Channel FFT Analyzer (CA-1000 Averager malfunctioned during the pilot runs). With the trigger pulse on one channel, EEG averages are reduced one channel at a time from magnetic tape. Also because of the limitations of the Nicolet, automatic eye artifact

rejection is no longer available.

Tracking Task

Setups for the three primary tasks used in the dual task conditions are shown in Fig 5. All three are displayed on an Audiotronics 6-inch video monitor at a distance of approximately 102 cm from the subject's eyes. The tracking task is completely implemented in hardware. A simple diagram of the tracking display screen is shown in Fig 6. The subject attempts to keep the moving cursor (represented by empty rectangle in Fig 6) on the fixed target (represented by the hash-marked rectangle in Fig 6). The tracker combines control input from the joystick with positive feedback from the system output. The weighted sum of the two voltages is multiplied by predetermined values and sent to an integrator. The integrator RC time constant multiplies the integral of the input voltage by 1/RC. The output of the system goes back through a fixed-setting potentiometer to be recombined with subsequent input voltages, repeating the cycle. The system is inherently unstable. The response increases exponentially for any input that is not dependent on the output. The hardware also measures operator performance keeping track of integrated error and number of control losses. A Lambda setting selects the rate of exponential increase of the output which determines the cursor control

TRACKING TASK



MATH AND PROBABILITY TASKS

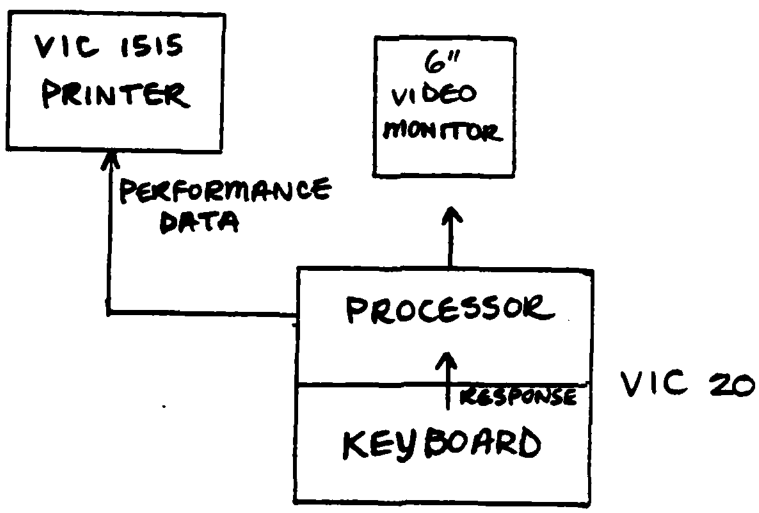


Fig 5. Primary Task Setups

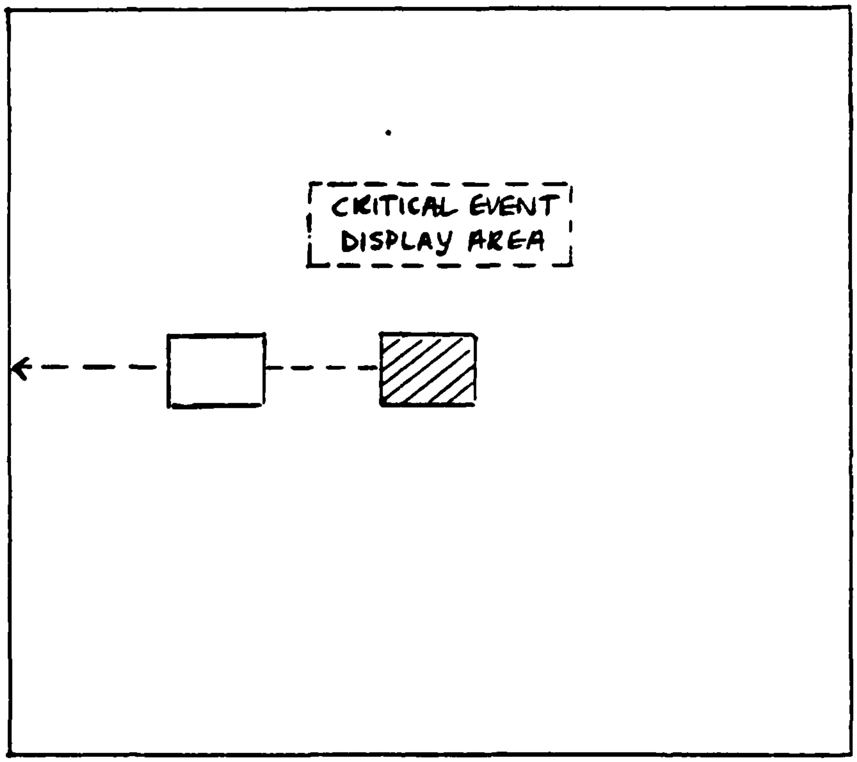


Fig 6. Tracking Task Display Screen

difficulty. The subject uses a single-axis (left-right) joystick with mild spring loading to the center position and a travel of approximately 45 degrees from side to side. The tracking task is started and stopped manually and the integrated error and number of control losses are displayed on the front of the tracking unit.

Mental Math Task

The mental math task is programmed in basic and loaded from cassette into a Commodore VIC-20 computer using the Commodore C2N cassette drive. The VIC-20 is expanded with a Commodore VIC-1111 16K RAM cartridge for additional program storage. The program randomly presents simple addition and subtraction problems with the following constraints: (1) only the numbers from 1 to 9 are used in the problems and answers; (2) the correct answer cannot be 5; (3) approximately half of the problems have an answer greater than 5; (4) when problems are solved from left to right, cumulative intermediate totals are positive numbers; (5) successive problems are not identical.

Maximum display time for each problem is 5 seconds. Problems are removed from the screen sooner if a response is made, whether correct or incorrect. The 5.5-second ISI is composed of the 5-second display time and a .5-second blank screen between items. One block of trials lasts

just over three minutes. The subject responds on the VIC-20 keyboard. The program records reaction time and correctness of each response which are sent to a Commodore VIC-1515 printer along with the number of problems presented, the percent correctly answered, the mean and standard deviation of the reaction times.

Probability Monitoring Task

The probability monitoring task is also programmed in basic and loaded from cassette into a Commodore VIC-20 computer using the Commodore C2N cassette drive. Again, the VIC-20 is expanded with a Commodore VIC-1111 16K RAM cartridge for additional program storage. Fig 7 diagrams the display screens for both the 1-dial and 3-dial conditions. When no signal (left or right bias) is present, the program moves the pointer to each of the six dial positions with equal probability. On the 3-dial display, pointer movement for each dial is independent of the other dials. The pointer changes positions at a rate of two moves per second. At some random point in time, the pointer movements for one dial cease to be random and appear more frequently on one side of the dial. The objective is to detect the bias and depress the appropriate response key. Reaction time is measured from onset of pointer bias to correct key depression. If a bias remains undetected for 30 seconds (or over 60 pointer

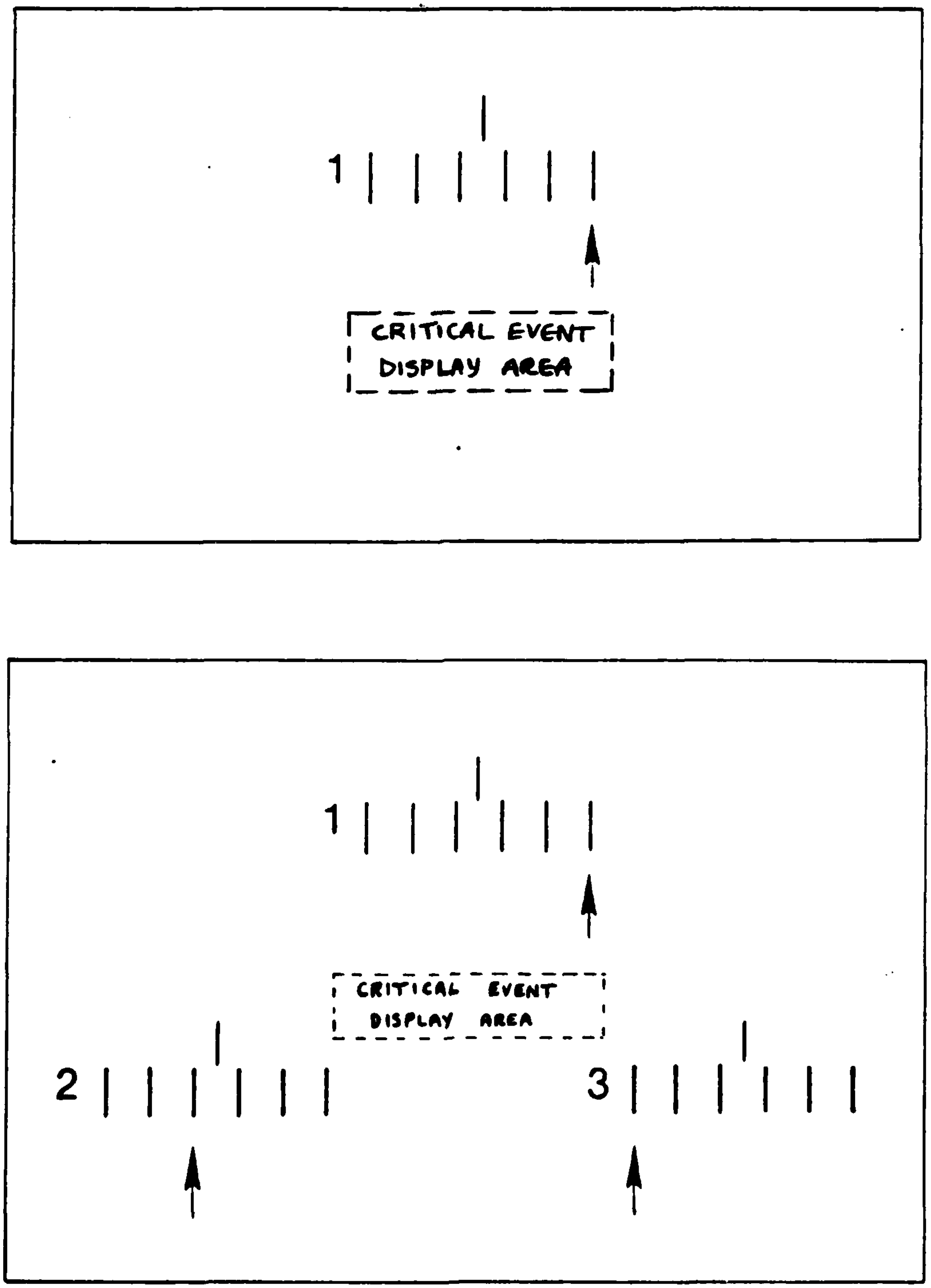


Fig 7. 1-Dial and 3-Dial Probability Monitoring Screens

movements), then it automatically resets to the unbiased condition. Movement of the pointer during a bias is random within the proportional constraints of the bias. Furthermore, biases are equally likely to be toward the right or left half of the dial. Responses are made on the VIC-20 keyboard. The program records the start time, stop time, and dial number of each bias. It also records the time and dial number indicated by each subject response. These data are sent to a VIC-1515 printer following completion of each appropriate condition.

VI RESULTS

When the data were read from the magnetic tape it was discovered that noise of varying intensity had been introduced onto the two most important trigger pulse channels. Furthermore, many of the trigger pulses were reduced in amplitude and duration. Since the trigger pulses were carefully checked before the experiment, it could only be assumed that the pulses were altered in the recording process. Because of the equipment problems, recognizable evoked potentials were extracted for only four subjects. Even among the four subjects reported here, some of the data could not be recovered. As a result, a rigorous statistical analysis of the results was not attempted. Instead, the evoked potentials which could be obtained were plotted for descriptive interpretation. Though such analysis is severely limited and valid conclusions cannot be drawn from four data points, certain trends were observed which may prove valuable in guiding future research.

Table I lists the mean reaction times for each condition and subject along with the number of critical events (out of 15) the subject detected within 1 second of stimulus presentation. Figures 8 through 71 in Appendix B show the EP plots for each subject and condition. Hash marks on the horizontal axis represent .1 seconds each. Hash marks on the vertical axis represent increments of

TABLE I

Critical Event Reaction Times/No. of Hits

(reaction time in milliseconds)

Cond No.	Subject Identification Number 1	2	3	4	Average
0	517/14	583/10	625/7	528/11	563/10.5
1	455/14	620/6	564/11	594/14	558/11
2	454/14	642/14	526/13	502/13	531/13.5
3	618/14	689/14	629/15	582/14	629/14
4	625/15	588/14	575/15	544/15	585/15
5	604/15	757/13	597/14	662/15	655/14
6	434/15	583/11	585/15	514/15	529/14
7	539/12	544/10	606/11	570/15	565/12
8	714/9	650/8	722/11	674/13	690/10
9	689/7	457/6	659/5	763/6	642/6
10	596/9	608/9	744/7	589/10	634/9
11	670/7	588/8	0/0	668/10	481/6

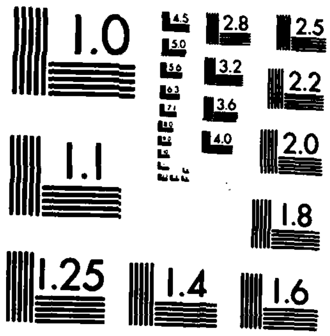
100 millivolts positive or negative from baseline. Vertical lines at 156 ms indicate onset of the stimulus. To obtain the latency of a waveform feature, 156 ms must be subtracted from the time read on the horizontal axis. The P525 component was hypothesized to have a parietal maximum. As a result, except for the spatial distribution data in experiment D, all comparisons were made using ERP data from the parietal electrode site.

Experiment A

Experiment A compared the results from condition 0 to those from condition 1. Condition 0 partially replicated Wilson, Ward, and Hahn's experiment with rest periods following each critical event. In condition 1, the rest periods were eliminated. Two factors combined to further limit the validity of the results from Experiment A. First, the trigger pulses associated with the non-critical events in condition 0 were not recorded for any of the 4 subjects which provided useful data. To salvage what comparison could be made, evoked potentials from the preceding events (those containing three consecutive ones which immediately precede the critical event) were compared to the evoked potentials from the critical events. Data reported for Experiment E suggest that the comparison may still give a rough idea of whether the P525 component is apparent for the critical event. Trigger

AD-A141 335 TRANSIENT EVOKED POTENTIAL IN A CRITICAL EVENT DETETTION TASK(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING S A HUDDLESON FEB 84 AFIT/GSO/EE/84M-1 2/3

UNCLASSIFIED F/G 5/10 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

pulses for non-critical events were obtained for the condition without rest periods after each critical event (condition #1). Hence, the proper comparison between evoked potentials elicited by critical vs. non-critical events could be made. In addition, the reaction time data indicate subjects had trouble detecting critical events when the stimulus duration was only 50 ms. Evidence of this difficulty first appeared during the trial runs and influenced the decision to use a 150 ms stimulus duration in other conditions that did not manipulate duration as an independent variable.

The critical event stimulus for the partial replication did not elicit clearly recognizable evoked potential components for subject #1 (Fig 8). Positive "bulges" were elicited at about 300 ms and 450 ms after onset of the preceding event stimulus. Behavioral measures indicate that subject #1 responded within 1 second to 14 of the 15 critical events with a mean reaction time of 517 ms seconds and a standard deviation of 91 ms. But 13 false positives were also recorded.

Results for subject #1 were not much more evident when the rest period following each critical event was removed (Fig 9). The critical event elicited weak indications of a small positive "bulge" at about 300 ms and another larger one at around 450 to 500 ms. The non-critical event elicited no discernable evoked potential components. The behavioral data indicate

subject #1 responded to 14 of the 15 critical events. Mean reaction time for condition #1 was 455 ms with a standard deviation of 136 ms. One reaction time was too quick to be anything but a guess. Although, the absence of clearly defined components made comparison difficult, the EP elicited by critical events in condition #1 appeared very similar to the EP from critical events in condition 0. The only noticable differences were a slightly higher amplitude for the 450 ms to 500 ms "bulge" and a slightly longer latency for the smaller "bulge" (closer to 350 ms).

The critical event elicited a high, positive peak at about 350 ms in condition 0 for subject #2 (Fig 10). Some rather ill-defined positivity also occured at about 525 ms. The EP for the preceding event also had the high peak at 350 ms but had no discernable peak at longer latencies. The mean reaction time for subject #2 in condition #0 was 583 ms with a standard deviation of 80 ms. The subject pressed the response button within 1 second after 10 of the 15 critical events.

During condition 1, EPs from both the critical and non-critical events for subject #2 contained the same high peak at about 350 ms (Fig 11). The non-critical event elicited more positivity around 525 ms than the critical event. Whether or not the subject detected enough of the critical events to reliably reflect in an averaged evoked potential cannot be confirmed by the behavioral data. The

subject pressed the response button within 1 second after only 6 of the 15 critical event stimuli with a mean reaction time of 620 ms and standard deviation of 79 ms. Hence, the EP for subject #2 in condition 1 is of doubtful validity. Doubt is also cast on any comparison between the critical event EP in condition 0 to the critical event EP in condition 1. Again, the two EPs look very similar.

Behavioral data for subject #3 in condition 0 confirmed detection of only 7 of the 15 critical events with a mean reaction time of 625 ms and a standard deviation of 145 ms. As might be expected, the corresponding EPs (Fig 12) did not reflect clearly defined components. Some evidence of a peak at about 300 ms occured for both critical and preceding events.

The behavioral data for condition 1 confirmed detection of 11 of the 15 critical events with a mean of 564 ms and a standard deviation of 91 ms. Positive peaks seemed to occur at about 300, 400, and 500 ms. The P500 elicited by the critical event clearly indicated a higher amplitude than the non-critical event. Once again, the critical event EPs for conditions 0 and 1 were very similar (Fig 12 and 13).

Behavioral data for subject #4 confirmed that 11 of the 15 critical events were detected in condition 0 with a mean reaction time of 528 ms and a standard deviation of 44 ms. In condition 1, 14 of the 15 critical events were detected with a mean reaction time of 594 ms and a

standard deviation of 77 ms. But no clearly discernable components were apparent (Fig 14 and 15).

Experiment B

Experiment B examined the waveforms elicited when stimulus durations were increased to 150 ms (condition 2), to 1 second (condition 3), and to random durations between 1.3 and 2.8 seconds (condition 4), and between 1.45 and 2.95 ms (condition 5). In general, the behavioral data indicated the subjects had much less trouble detecting the critical events when stimulus durations were longer. Average mean reaction times for all four subjects were 558 ms for condition 1, 531 ms for condition 2, 630 ms for condition 3, 585 ms for condition 4 and 655 ms for condition 5. The EPs elicited by the 150 ms stimuli generally had the most discernable components.

Behavioral data confirmed that subject #1 recognized 14 of the 15 critical events for conditions 2 and 3 and all 15 critical events for conditions 4 and 5. Mean reaction time for condition 2 was 454 ms with a standard deviation of 62 ms. Reaction times for conditions 3, 4, and 5 jumped to 618 ms, 625 ms, and 604 ms with standard deviations at 234 ms, 130 ms, and 86 ms, respectively. The wide range in reaction times may have contributed to the loss of component definition reflected in the EPs for conditions 3, 4, and 5 (Fig 17, 18, and 19).

The EP elicited by the 150 ms critical event stimuli for subject #1 contained a very clear EP component peaking at nearly 500 ms (Fig 16). This peak occurs after the response since its latency is longer than the mean reaction time. The non-critical event for the same condition clearly did not contain the same large, high amplitude peak. This was the first clear support for the earlier findings by Wilson, Ward, and Hahn.

Behavioral data confirmed that subject #2 recognized 14 of the 15 critical events for conditions 2, 3, and 4 and 13 of the 15 critical events for condition 5. Mean reaction time for condition 2 was 642 ms with a standard deviation of 105 ms. Reaction time for condition 3 was 689 ms with a standard deviation of 135 ms. Reaction time for condition 4 was 588 ms with a standard deviation of 135 ms. Reaction time for condition 5 was 757 ms with a standard deviation of 122 ms.

The EP elicited by the 150 ms critical event of condition 2 (Fig 20) appears to contain positive components at about 350 ms and nearly 500 ms. But the non-critical event for the same condition shows very similar components. The 1 second critical event stimulus of condition 3 (Fig 21) has crude components at about 350 ms and 500 ms which do not appear in the non-critical event for the same condition. The critical event in condition 4 (Fig 22) elicited a large positive peak at 550 ms after the stimulus. The peak was not elicited by the

non-critical event in that condition. The non-critical event did appear to elicit a positive peak at about 300 ms which did not appear for the critical event. Condition 5 did not elicit recognizable components for subject #2 (Fig 23).

Behavioral data confirmed that subject #3 recognized 13 of the 15 critical events for condition 2, all 15 critical events for conditions 3 and 4, and 14 of the 15 critical events for condition 5. Mean reaction time for condition 2 was 526 ms with a standard deviation of 71 ms. Reaction time for condition 3 was 629 ms with a standard deviation of 143 ms. Reaction time for condition 4 was 575 ms with a standard deviation of 98 ms. Reaction time for condition 5 was 597 ms with a standard deviation of 90 ms.

The EP elicited by the critical event in condition 2 (Fig 24) contained a larger component at a latency of about 500 ms than the non-critical event. Otherwise, the critical and non-critical event waveforms were very similar to each other. In condition 3 (Fig 25), the critical event elicited a large peak at about 600 ms (note that the reaction time was also about 100 ms slower than condition 2). Again, the non-critical event did not elicit any similar component. The same difference between critical and non-critical event EPs could be observed in condition 4 with crude evidence of a component in the 500 to 600 ms range (Fig 26). But components are not

discernable in condition 5 (Fig 27).

Behavioral data confirmed that subject #4 recognized 13 of the 15 critical events for condition 2, 14 of the 15 critical events for condition 3, and all 15 critical events for conditions 4 and 5. Mean reaction time for condition 2 was 502 ms with a standard deviation of 86 ms. Reaction time for condition 3 was 582 ms with a standard deviation of 159 ms. Reaction time for condition 4 was 544 ms with a standard deviation of 153 ms. Reaction time for condition 5 was 662 ms with a standard deviation of 162 ms.

The critical event in condition 2 elicited more positive-going wave at around 500 ms than the non-critical event (Fig 28). But the component was not very clear and late components in conditions 3, 4, and 5 were increasingly unclear (Fig 29, 30, and 31).

Experiment C

Experiment C manipulated the method of responding rather than the stimulus. The waveform elicited by the motor response was compared to the waveform elicited by a counting response. The EPs elicited by critical events for subjects #1 and #4 when no motor response was required (Fig 32 and 35) contained clear large components with a latency of about 500 ms. The same large components were not elicited by non-critical events. Furthermore, when

the EPs for subjects #1 and #4 for condition 12 (Fig 32 and 35) were compared to the EPs elicited by the same subjects in condition 2 (Fig 16 and 28), the waveforms were remarkably similar. Condition 12 for subjects #2 and #3 failed to elicit recognizable EP components (Fig 33 and 34).

Experiment D

Up to this point all comparisons were made using EPs from the parietal electrode site because the P525 component was hypothesized to have a parietal maximum. Results from experiment D tended to confirm the hypothesis. To investigate the spatial distribution of the positive component in the latency region around 500 ms (P500), EPs from the midline parietal, central, and frontal scalp locations were compared. The EPs were selected from condition 2 because condition 2 had generally produced the clearest components at the parietal site. The P500 component for subject #1 (Fig 16, 36, and 37) had a parietal maximum and a frontal minimum amplitude (Pz>Cz>Fz). For subject #2 (Fig 20, 38, and 39), the Pz measurement of the component was larger overall than the other locations and the frontal was again the minimum (Pz>Cz>Fz). Subject #3 (Fig 24, 40, and 41) showed the parietal and central amplitudes about equal with the frontal amplitudes lower (Pz=Cz>Fz). Subject #4 (Fig 28,

42, and 43) had a larger parietal component and smaller central and frontal component measurements (Pz>Cz=Fz). The difference in P500 amplitude between critical and non-critical events was also maximum at the parietal site while sometimes non-existent at the other electrode sites.

Experiment E

Experiment E compared the waveform elicited by the event (containing 3 consecutive ´1´s) which immediately preceed the critical event with the waveform elicited by other non-critical events. The preceding events examined for experiment E were from condition 2. The preceding event failed to elicit clear components for any of the four subjects. In all cases, the preceding event failed to elicit components distinctive in size from a non-critical event (Fig 44 through 47).

Experiment F

In experiment F, the critical event task was the secondary task in a dual task paradigm. ERP´s from critical events during 2 difficulty levels for each of 3 primary tasks were compared. It became apparent during the trial runs that the critical event detection task interfered with the primary tasks much more than anticipated. The interference was especially strong when the primary task was math or probability monitoring. The

interference was clearly reflected in the reaction time data, the EPs, and the post-experiment surveys.

The interference of the critical event detection task on tracking performance was evident from the increase in tracking error between conditions 6a/7a and conditions 6/7. When the critical event detection task was introduced during the easy level tracking, the average integrated error jumped from 432 to 718. Scores for the difficult level of tracking generally verified both the greater difficulty of the primary task and the interference of the critical event task.

Behavioral data confirmed that on the average, subjects detected 14 of the 15 critical events in condition 6 (easy tracking) and 12 of the 15 in condition 7 (difficult tracking). Table II lists the tracking performance score for each subject by condition. Average mean reaction time for the four subjects was 531 ms when the critical event detection task was presented alone (condition 2) compared to 529 ms with easy tracking and 565 ms with hard tracking.

In the data for all four subjects, EPs elicited by the critical event in conditions 6 and 7 (Fig 48 through 55) had a larger P500-type component than EPs elicited by the non-critical event. For subject #1, the P500 elicited by the critical event in condition 6 (Fig 48) was slightly higher than in condition 2 (Fig 16). Furthermore, the P500 elicited by the critical event in condition 7

TABLE II

Tracking Integrated Error Scores

Cond No.	Subject Identification Number				Average
	1	2	3	4	
6	569	988	879	438	718
6a	309	547	526	345	432
7	1225	483	1394	671	943
7a	817	988	1188	567	890

(Fig 49) was slightly lower than the critical event in condition 6 (Fig 48). For critical events in condition 6, subject #2 (Fig 50) showed a slight reduction of the P500 compared to condition 2 (Fig 20) but no difference when difficulty of tracking was increased (Fig 51). Subjects #3 and #4 showed a similar reduction in P500 size for condition 6 (Fig 52 and 54), but again, no change from condition 6 to condition 7 (Fig 53 and 55).

Mental math performance measures indicated the critical event task interfered with the math task and confirmed the increase in mental math difficulty. Table III summarizes the mental math performance for each subject by condition. Subjects averaged 94% correct with a mean reaction time of 1386 ms for easy math alone (condition 8a), 81% correct with a mean reaction time of 2525 ms for hard math alone (condition 9a), 92% correct with a mean reaction time of 1088 ms for easy math with critical event task (condition 8), and 74% correct with a mean reaction time of 2364 ms for hard math with the critical event task.

Reaction time data confirmed that subject #1 detected only 9 of the 15 critical events in condition 8 and 7 of the 15 in condition 9, subject #2 detected only 8 of the 15 critical events in condition 8 and 6 of the 15 in condition 9, subject #3 detected 11 of the 15 critical events in condition 8 and only 5 of the 15 in condition 9, and subject #4 detected 13 of the 15 critical events in

TABLE III

Mental Math: Percent Correct/Mean Reaction Time

(reaction time in milliseconds)

Cond No.	Subject Identification Number				Average
	1	2	3	4	
8	81/1298	96/946	98/1197	93/910	92/1088
8a	91/3071	93/751	95/881	96/843	94/1386
9	58/2476	78/2127	89/2278	72/2575	74/2364
9a	62/3503	80/1882	96/2410	88/2304	81/2525

condition 8 and only 6 of the 15 in condition 9. Average mean reaction time for the four subjects went from 531 ms when the critical event detection task was presented alone (condition 2) to 690 ms with easy math and to 642 ms with hard math.

The EP results (Fig 56 through 63) are difficult to interpret. Their validity is very doubtful in light of the behavioral response data. For example, the P500 component elicited for subject #1 in condition 8 (Fig 56) appears for the non-critical event but not for the critical event. The EEGs for subject #2 in conditions 8 and 9 (Fig 58 and 59) did not contain recognizable components. The critical events for subject #3 showed a reduction in size from condition 2 (Fig 24) to condition 8 (Fig 60) and a further reduction from condition 8 (Fig 60) to condition 9 (Fig 61). These data are unreliable, however, due to the low number of critical event detections confirmed by button response. EP data for subject #4 did not contain recognizable components.

Probability monitoring performance measures indicated the critical event task interfered with the monitoring task and confirmed the increase in monitoring difficulty. Table IV summarizes the probability monitoring performance of each subject by condition. On the average, subjects detected 75% of the biases with a mean reaction time of 5 seconds and no false positives for easy monitoring alone (condition 10a). They detected only 25% of the biases

TABLE IV

Probability Monitoring Performance

Percent Detected/Mean Reaction Time/False Alarms

(reaction time in seconds)

Cond No.	Subject Identification Number				Average
	1	2	3	4	
10	100/10/2	100/6/0	100/9/0	100/6/10	100/8/3
10a	100/5/1	100/10/0	100/6/0	0/0/0	75/5/0
11	0/0/2	0/0/1	67/20/2	100/15/13	42/9/5
11a	0/0/1	33/28/1	33/38/2	33/34/4	25/25/2

with a mean reaction time of 25 seconds and 2 false positives for hard monitoring alone (condition 11a). The subjects averaged 100% of the biases with a mean reaction time of 8 seconds and 3 false positives for easy monitoring with the secondary critical event task (condition 10). Finally, they averaged 42% of the biases with 9 false positives for hard monitoring with the critical event task (condition 11).

Behavioral data confirmed subject #1 detected only 9 of the 15 critical events in condition 10 and 7 of the 15 in condition 11, subject #2 detected only 9 of the 15 critical events in condition 10 and 8 of the 15 in condition 11, subject #3 detected only 7 of the 15 critical events in condition 10 and none of the 15 in condition 11, and subject #4 detected 10 of the 15 critical events in both conditions 10 and 11. Average mean reaction time for the four subjects was 531 ms when the critical event detection task was presented alone (condition 2) compared to 634 ms with easy monitoring and 642 ms with hard monitoring.

The EEG results for conditions 10 and 11 (Fig 64 through 71) do not contain evoked potential components for any of the subjects. Such results were consistent with lack of behavioral evidence that the subject detected enough of the critical events to produce reliable EP averages.

VII DISCUSSION

The "conclusions" from this study must be considered tentative observations because the results lacked adequate sample size and statistical significance was not demonstrated. Several observations may provide useful guidance for future research in related areas.

Observations

The most significant observation was the prominent P500 component elicited by the critical event. The P500 appeared to be related to task relevance because the prominent component did not appear following non-critical events.

The results from experiment D consistently demonstrated that the P500 component had a spatial distribution characterized by a parietal maximum and a frontal minimum. This distribution is similar to the distribution reported for the P3b component. It is also similar to the P3b in that one of its major antecedent conditions is task-relevance.

The additional presence of a P300 component appeared possible but was not confirmed. Additional research is needed to obtain a significant sample size and fully extract the waveform components. If the P300 is also present, then critical event detection and other similar

tasks may be useful in providing two, non-unitary, late positive components. Manipulating other factors like probability may lead to breakthroughs in understanding the processing of complex tasks.

The majority of the EPs from conditions 0 and 1 failed to show clear components. Some gave clear evidence of a critical event-related positive peak around the 500 ms latency range. One consistent result was the similarity between waveforms elicited in condition 0 to waveforms elicited in condition 1. There does not seem to be any confounding of the waveform by CNV resolution or other factors peculiar to the original grouped presentation of stimuli culminating in a critical event followed by a rest period.

Experiment B generally demonstrated that the transient evoked response, as it was used in this experiment, is not a good tool for detecting cognitive events when stimulus durations are increased. The EP components, and with them the capability to detect cognitive events, deteriorated beginning with the 1 second stimulus duration and becoming generally worst as the stimulus duration increased. Of the stimulus durations in the experiment, 150 ms seemed to provide the best balance between readability and EP component definition.

Only two of the subjects provided useful information to check motor interference in the EP waveform. The limited data available suggest that the the waveforms are

not confounded to any great degree by psychomotor potentials. The waveforms elicited in condition 12 appeared very similar to the waveforms elicited in condition 2.

None of the data from experiment E supports Wilson, Ward, and Hahn's finding of an intermediate amplitude component larger than the non-critical event but smaller than the critical event. Generally, EPs for the preceding event had the same characteristics as EPs for the non-critical event.

Experiment F demonstrated that the critical event detection task used in this experiment was too intrusive (interfered too much with the primary task) to be of value as a workload metric. This does not appear to be the direction to go in a search for a cognitive workload metric unless dual task interference can be substantially reduced. As expected, the dual task conditions demonstrated stronger interference between the critical event detection task and math or probability monitoring than tracking.

Recommendations

The following suggestions and recommendations for future research are offered based on the findings and failures of this study:

(1) Experiments to investigate competition for cognitive resources need to be designed in such a way that competing cognitive tasks use non-competing input and output modalities. For example, Donchin and Wickens have noted that workload effects appear to be more accurately measured when the probe stimuli do not use the same modality as the workload task (41:13-14). If the task is visual, for example, the probes should be auditory. Response modalities can also interfere with each other.

(2) Donchin and Wickens further note that auditory probes may be more sensitive to changes in workload (41:14-15). Auditory workload metrics for the cognitive domain need to be developed.

(3) Develop a reliable, standard method for observing the brain potentials for each trial and aligning components prior to averaging the trials.

(4) Develop an effective and adaptable, on-line system for the removal of occular artifacts during EEG experiments.

(5) Measure the reaction time of each subject to onset of a stimulus which requires no processing in order to establish a baseline response time.

(6) Control and investigate the hemispheric interference of using right and left hands in dual task paradigms.

(7) One key variable that is known to influence late positive components is stimulus probability. This study

demonstrated the effect of task relevance on the P500 component while holding probabilities constant. Another study is needed to investigate the effect of changes in probability on the EP components elicited by the critical event. For example, whether or not the earlier P300 or the later P500 components respond to changes in probability would be of theoretical value in sorting out the various late positive components and their relationship to the processing functions and stages of the human brain.

Improvements like those listed above may allow transient evoked potentials to provide validation of inferences made on the basis of other behavioral and physiological measures about the cognitive events within the human brain. But as a stand-alone measure, at present, the transient evoked potential appears to require too much control to be of use in the operational setting.

APPENDIX A: Critical Event Detection Task Programs

Condition 0

```
1 printchr$(142):poke52,48:poke56,48: clr:poke56334,peek
(56334)and254
2 poke1,peek(1)and251:fori=0to511:
pokei+12288,peek(i+53248):next
3 poke1,peek(1)or4:poke56334,peek(56334)or1:poke
53272,(peek(53272)and240)+12
4 for i=12504 to 12527: readc: poke i,c:next
6
data24,24,24,24,24,24,24,0,0,0,0,24,0,0,0,0,60,102,102,102
,102,102,60,0
10 poke53281,0:poke53280,0:poke56579,3:print"e"
12 dim rt(22)
15
a=56577:b1=249:b2=250:b3=252:b7=120:b0=248:f=1:f$="abcdefg
hijk"
18 for i=850 to 894:readc:poke i,c:next
19 data
160,0,162,0,142,127,3,173,1,221,10,144,25,200,208,247,232,
173
20 data
127,3,201,1,16,10,224,0,208,235,238,127,3,76,89,3,224,21,2
08
21 data 225,142,128,3,140,129,3,96
24 fori=832to844:read c:poke i,c:next
25 data
173,18,208,208,251,169,128,44,17,208,48,244,96,endinit
30 input"ssubject id";su$
34 read s$: if s$="endinit" goto 40
36 goto 34
40 for i=1 to 22: rt(i)=0: next
55 print"Sqqqqqqqqqqq";tab(19);"{e";
60 for se=1 to 18
70 read cs
80 td=ti+500
90 if ti=td goto 110
100 goto 90
110 for s=1 to abs(cs)
120 read s$: b=b0
140 if s=cs then b=b1: goto 180
150 if s=cs-1 then b=b2: goto 180
160 if s=1 then b=b3
180 sys 832
182 poke a,b
184 for i=1 to 27: next
186 poke a,b0
188 for i=1 to 34: next
190 print"Sqqqqqqqqqqq";tab(16);s$;
```

```
192 tp=ti
194 for i=1 to 25: next
200 print"Sqqqqqqqqqqq";tab(19);"{e";
210 sys 850
220 tr=(peek(897)*.014 +
peek(896)*3.614+peek(895)*925.223+.022)+50
225 if (s=cs) and (tr>1000) goto 255
230 if s=cs then rt(se)=tr: rt(19)=rt(19)+1:
rt(20)=rt(20)+rt(se)
235 if s=cs then rt(21)=rt(21)+rt(se)ç2:goto 255
245 if tr<1000 then rt(22)=rt(22)+1
255 td=tp+78+int(rnd(1)*90)
260 if ti>td goto 300
280 goto 260
300 next s
400 next se
405 if rt(19)=0 goto 440
410 rt(21)=(rt(21)-rt(20)ç2/rt(19))ç.5
420 rt(20)=rt(20)/rt(19)
440 s$="d"
450 print"send of 0: 1=redo 2=p&d 3=p 4=d 5=exit"
480 get s$: if s$="" goto 480
485 s=val(s$)
490 on s goto494,514,514,514,9999
494 restore: goto 34
514 if(s=2)or(s=3)then open 4,4
516 if(s=2)or(s=4)then open
8,8,9,"0:"+su$+mid$(f$,f,1)+",s,w"
519 if(s=2)or(s=3)thenprint#4,su$+mid$(f$,f,1),"rep"
521 if(s=2)or(s=4)thenprint#8,su$+mid$(f$,f,1),"rep"
523 h$=chr$(13): f=f+1
525 for i=1 to 22
530 if i<10thenr$=str$(i)+" ":goto559
532 if i<19thenr$=str$(i):goto559
535 on i-18 goto 540,545,550,555
540 r$=" tp": goto 559
545 r$=" me": goto 559
550 r$=" sd": goto 559
555 r$=" fp": goto 559
559 if(s=2)or(s=3)then print#4,r$,rt(i)
561 if (s=2)or(s=4) then print#8,r$,rt(i);h$;
570 next i
574 if(s=2)or(s=3)then close 4
576 if(s=2)or(s=4)then close 8
580 goto 440
999 data -5,}}^^}^^,^}}^^}},^}}}^}},}^}}^^^,}}^^^^^
1000 data 4,}^^^^}},}}^^}}},}}}^^}},}}}}^^}
1001 data 3,^^}}^}},^}}}^}},}}}}^}^
1002 data -5,}^^^}^},^}}^}^},^}}^}}^,^^^}^}},}^}^}^^
1003 data 5,}}^^}^^,}}}^^}^,}}^}}^^,^}^}}}^,}^^}}}}
1004 data 3,}}^^}}^,}^^}}}^,^^}}}}^
1005 data 5,^}}^}^},^}^}}^},}^^}}^^,^^}}}^^,^}}}}^^
1006 data 4,}}^^^^^,}}}^^}},}}^^}}},}}^}}}}
```

```
1007 data 4,}^^^^}},^}}^}}^,^}}}^}^,^}}}}}^^
1008 data 3,}}^^}}^,^}^}}}^,}^}}}}^
1009 data 5,^}^^^}},^^^^^}},^^}}^}},^}}}^}^,}}}}^}}
1010 data 3,}^}}^^},^^}}}^},^^}}}}^
1011 data -5,^^}}^^},}}^^^}},}^}^^}},^^^}}}^,^^}}^}}
1012 data 3,}}^}}^^,}}}^}}},}}}}^}}
1013 data 4,^^}}^^},}^}}^^^,^}}}^^},^}}}}}^^
1014 data 5,}}^^}}^,^}^^}}},}^}}^^},^^}}}^},}^}}}}^
1015 data 3,}^}}^}},}^}}}^^,}^}}}}^
1016 data 4,}}^^^}},}}^}}^^,}^^}}}^,^^^}}}}
9999 end
```

<u>All Other Conditions</u>

```
3 poke53281,0:poke53280,0:poke56579,7:print"e"
5
printchr$(142):poke52,48:poke56,48:clr:poke56334,peek(5633
4)and254
6
poke1,peek(1)and251:fori=0to511:pokei+12288,peek(i+53248):
next
7 poke1,peek(1)or4:poke56334,peek(56334)or1
8 poke 53272,(peek(53272)and240)+12
10 read s$: if s$="ends" goto 15
11 goto 10
15 for i=12504 to 12527: readc: poke i,c: next
18 for i=0 to 44: read c: poke 850+i,c: next
24 for i=832 to 844: read c: poke i,c: next
26 a=56577:b1=249:b2=250:b3=252:b7=120:b0=248:pt$="    {
"
27 f=1: n$="1234567890"
28 dim rt(19,12),d$(12)
29 print"Sqqqqqqqqqqq";tab(16);pt$
30 input"ssubject id";su$
32 input"condition?  (1-12)";c
35 d=0
40 if c<2 then d=50: dc=25
45 if (c=2) or (c>5) then d=150: dc=100
50 print"Sqqqqqqqqqqq";tab(16);pt$
52 td=ti+180
55 restore
65 i=c: if c>5 then i=c-5: if c>10 then i=c-10
70 read s$: if s$="c"+str$(i) goto 75
72 goto 70
75 for i=1 to 19: rt(i,c)=0: next i
80 if ti>td then 90
81 goto 80
90 for se=1 to 15
100 read cs
110 for s=1 to 5
120 read s$: b=b0
140 if s=cs then b=b1: goto 170
```

```
150 if s=cs-1 then b=b2: goto 170
160 if s=1 then b=b3: goto 170
170 if c=4 then print"sqqqqqqqqqqq";tab(16);pt$
180 sys 832
182 poke a,b
184 for i=1 to 27: next
186 poke a,b0
188 for i=1 to 54: next
190 print"sqqqqqqqqqqq";tab(16);s$: tp=ti
192 if d=0 goto 210
194 for i=1 to dc: next
200 print"sqqqqqqqqqqq";tab(16);pt$
210 sys 850
215 if c=3 then print"sqqqqqqqqqqq";tab(16);pt$
220
tr=(peek(897)*.014+peek(896)*3.614+peek(895)*925.223+.022)
+d
225 if (s=cs) and (tr>1000) goto 255
230
ifs=csthenrt(se,c)=tr:rt(16,c)=rt(16,c)+1:rt(17,c)=rt(17,c
)+tr
235 if s=cs then rt(18,c)=rt(18,c)+trç2:goto 255
245 if tr<1000 then rt(19,c)=rt(19,c)+1
255 td=tp+78+int(rnd(1)*90)
260 if ti>td goto 300
280 goto 260
300 next s,se
405 if rt(16,c)=0 goto 440
410 rt(18,c)=(rt(18,c)-rt(17,c)ç2/rt(16,c))ç.5
420 rt(17,c)=rt(17,c)/rt(16,c)
440 s$="d"
450 print"s";c;": 1=nx 2=p&d 3=p 4=d 5=c 6=id 7=ex"
480 get s$: if s$="" goto 480
485 s=val(s$)
490 on s goto495,514,514,514,32,30,54000
495 c=c+1: goto 35
514 if(s=2)or(s=3)then open 4,4
516 if(s=2)or(s=4)then open
8,8,9,"0:"+su$+mid$(n$,f,1)+",s,w"
517 a$=" c01   c02   c03   c04   c05   c06   c07   c08
c09   c10   c11"
519 if(s=2)or(s=3)then print#4,su$+mid$(n$,f,1)+a$
521 if(s=2)or(s=4)then print#8,su$+mid$(n$,f,1)+a$
523 h$=chr$(13): f=f+1
525 for i=1 to 19
530 if i<10thenr$=str$(i)+" ":goto 556
532 if i<16thenr$=str$(i):goto 556
535 on i-15 goto 540,545,550,555
540 r$=" tp": goto 556
545 r$=" me": goto 556
550 r$=" sd": goto 556
555 r$=" fp": goto 556
556 for k=1to11
```

```
557 d$(k)=str$(int(rt(i,k)))
558 if len(d$(k))<6then d$(k)=d$(k)+" ":goto 558
559 next k
566 if(s=2)or(s=3)then gosub 600
568 if(s=2)or(s=4)then gosub 650
570 next i
574 if(s=2)or(s=3)then close 4
576 if(s=2)or(s=4)then close 8
580 goto 440
600 print#4,r$;
610 for k=1to10:print#4,d$(k);:next:print#4,d$(11)
620 return
650 print#8,r$;
660 for k=1to10:print#8,d$(k);:next:print#8,d$(11);h$;
670 return
1001 data c 1,4,}^^^^}},}}^^}}},}}}^^}},}}}}^^},^}}^^}^
1002 data 3,^^}}^}},^}}}^}},}}}}^}^,}}}^^^^,^}^}}^}
1003 data 5,}}^^}^^,}}}^^}^,}}^}}^^,^}^}}}^,}^^}}}}
1004 data 3,}}^^}}^,}^^}}}^,^^}}}}^,}^}}^^},^^}}^}^
1005 data 5,^}}^}^},^}^}}^},}^^}}^^,^^}}}^^,^}}}}^^
1006 data 4,}}^^^^^,}}}^^}},}}^^}}},}}^}}}},^}^}^}}
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1008 data 3,}}^^}}^,^}^}}}^,}^}}}}^,^}}^}^},}}}^}^}
1009 data 5,^}^^^}},^^^^^}},^^}}^}},^}}}^}^,}}}}^}}
1010 data 3,}^}}^^},^^}}}^},^^}}}}^,}^^}^^^,}}^}}^^
1011 data 3,}}^}}^^,}}}^}}},}}}}^}},^^^^^}},}}^^^}}
1012 data 4,^^}}^^},}^}}^^^,^}}}^^},^}}}}^^,}^^}^}}
1013 data 5,}}^^}}^,^}^^}}},}^}}^^},^^}}}^},}^}}}}^
1014 data 3,}^}}^}},}^}}}^^,}^}}}}^,^^^^^}},}^}}^^}
1015 data 4,}}^^^}},}}^}}^^,}^^}}}^,^^^}}}},^^^^^}}
2001 data c 2,4,}^^^^}},}}^^}}},}}}^^}},}}}}^^},^}}^^}^
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2014 data 3,}}^^}}^,^}^}}}^,}^}}}}^,^}}^}^},}}}^}^}
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3002 data 3,^^}}^}},^}}}^}},}}}}^}^,}}}^^^^,^}^}}^}
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3008 data 4,^^}}^^},}^}}^^^,^}}}^^},^}}}}^^,}^^}^}}
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3009 data 4,}^^^^}},}}^^}}},}}}^^}},}}}}^^},^}}^^}^
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4014 data 4,}}^^^}},}}^}}^^,}^^}}}^,^^^}}}},^^^^^}}
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5004 data 4,}^^^^}},^}}^}}^,^}}}^}^,^}}}}^^,}^}^}^^
5005 data 5,}}^^}^^,}}}^^}^,}}^}}^^,^}^}}}^,}^^}}}}
5006 data 5,^}^^^}},^^^^^}},^^}}^}},^}}}^}^,}}}}^}}
5007 data 3,}^}}^^},^^}}}^},^^}}}}^,}^^}^^^,}}^}}^^
5008 data 3,}}^^}}^,}^^}}}^,^^}}}}^,}^}}^^},^^}}^}^
5009 data 3,}}^^}}^,^}^}}}^,}^}}}}^,^}}^}^},}}}^}^}
5010 data 5,}}^^}}^,^}^^}}},}^}}^^},^^}}}^},}^}}}}^
5011 data 3,}^}}^}},}^}}}^^,}^}}}}^,^^^^^}},}^}}^^}
5012 data 4,}}^^^^^,}}}^^}},}}^^}}},}}^}}}},^}^}^}}
5013 data 5,^}}^}^},^}^}}^},}^^}}^^,^^}}}^^,^}}}}^^
5014 data 3,}}^}}^^,}}}^}}},}}}}^}},^^^^^}},}}^^^}}
5015 data 4,}}^^^}},}}^}}^^,}^^}}}^,^^^}}}},^^^^^}},ends
50000 data 24,24,24,24,24,24,24,0,0,0,0,24,0,0,0,0
50005 data 60,102,102,102,102,102,60,0
50010 data
160,0,162,0,142,127,3,173,1,221,10,144,25,200,208,247,232,
173
50020 data
127,3,201,1,16,10,224,0,208,235,238,127,3,76,89,3,224,21,2
08
50030 data 225,142,128,3,140,129,3,96
50040 data 173,18,208,208,251,169,128,44,17,208,48,244,96
54000 end
```
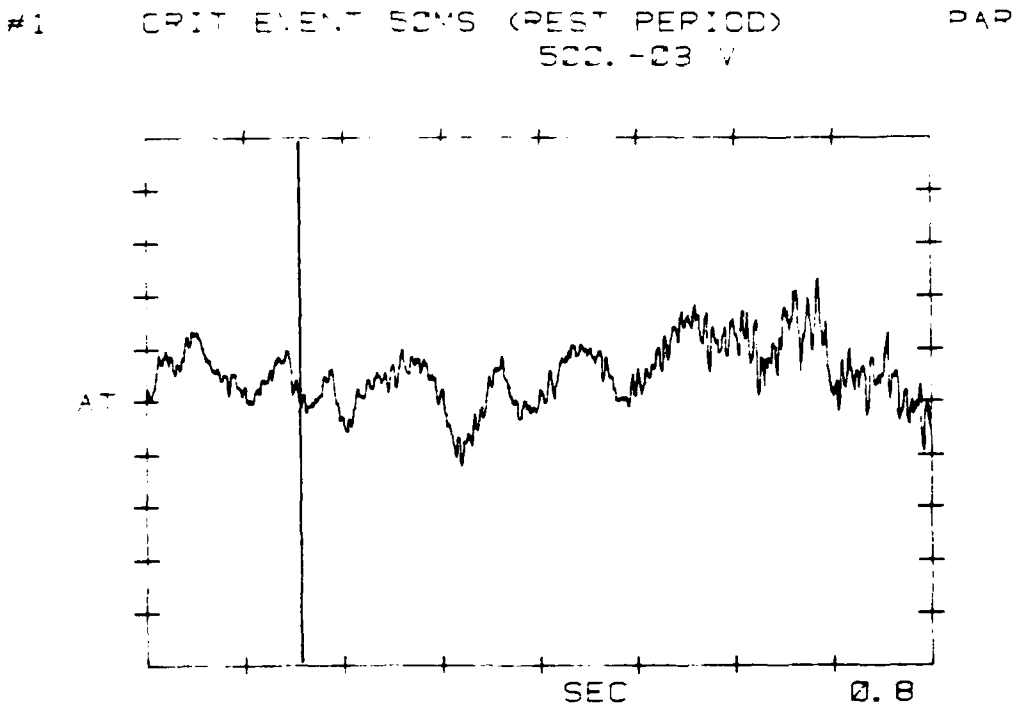

APPENDIX B: Transient Cortical Evoked Response Plots



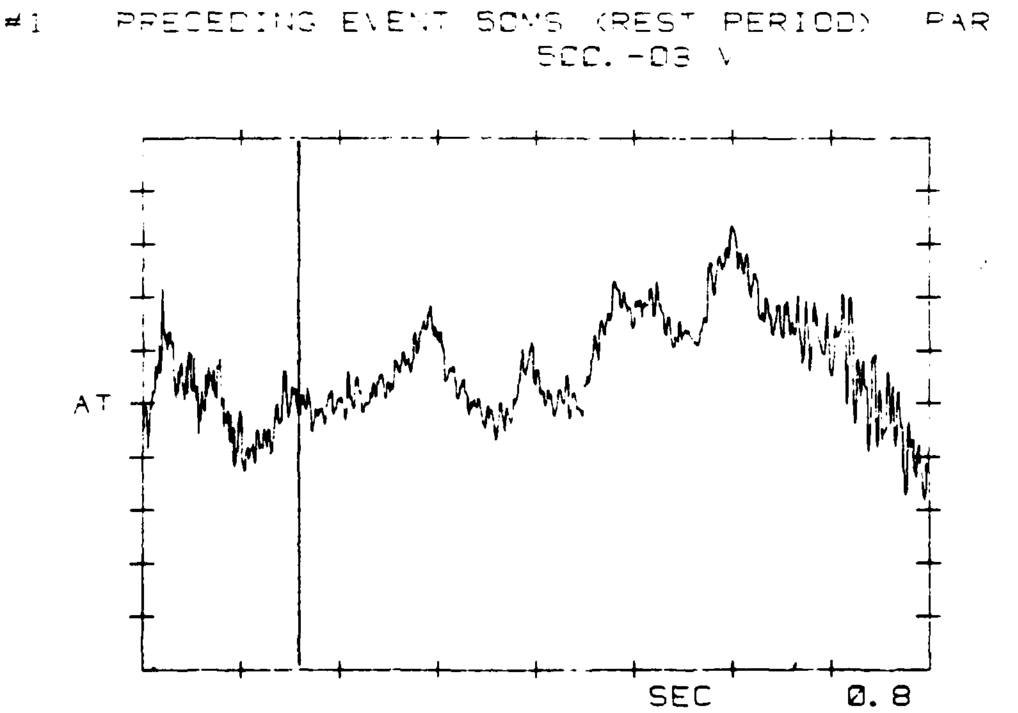
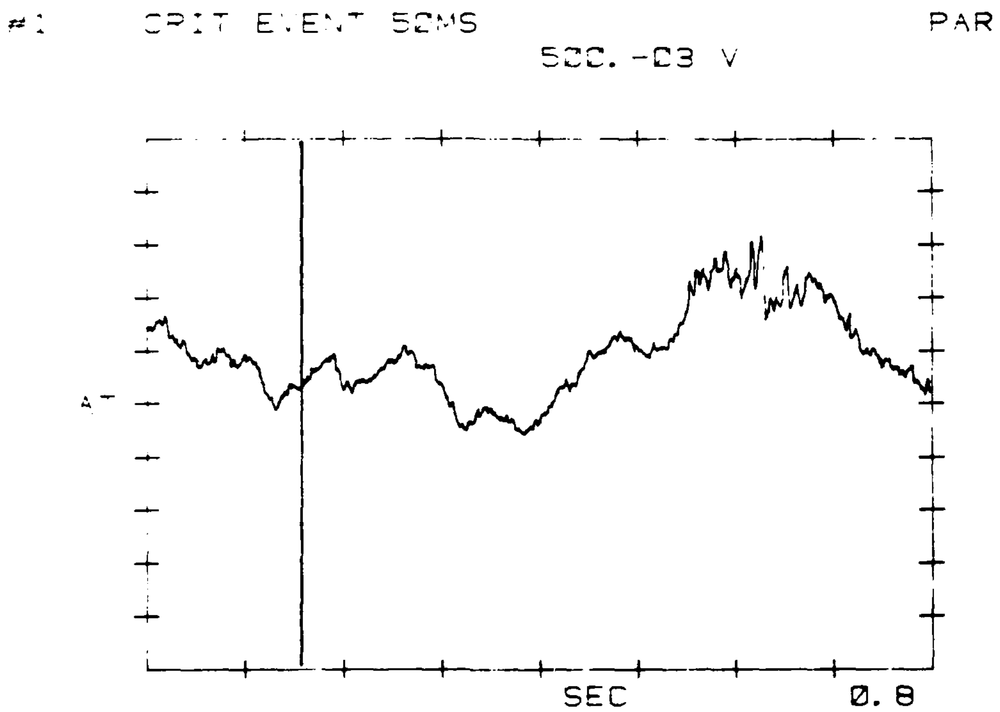


Fig 8. Condition 0/Subject 1



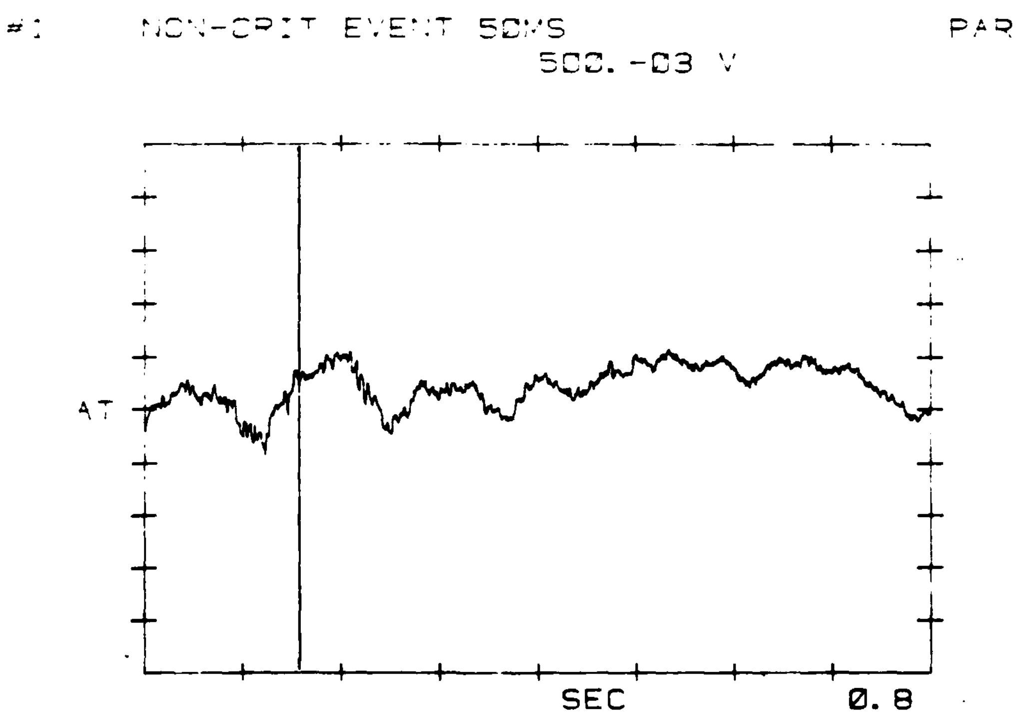
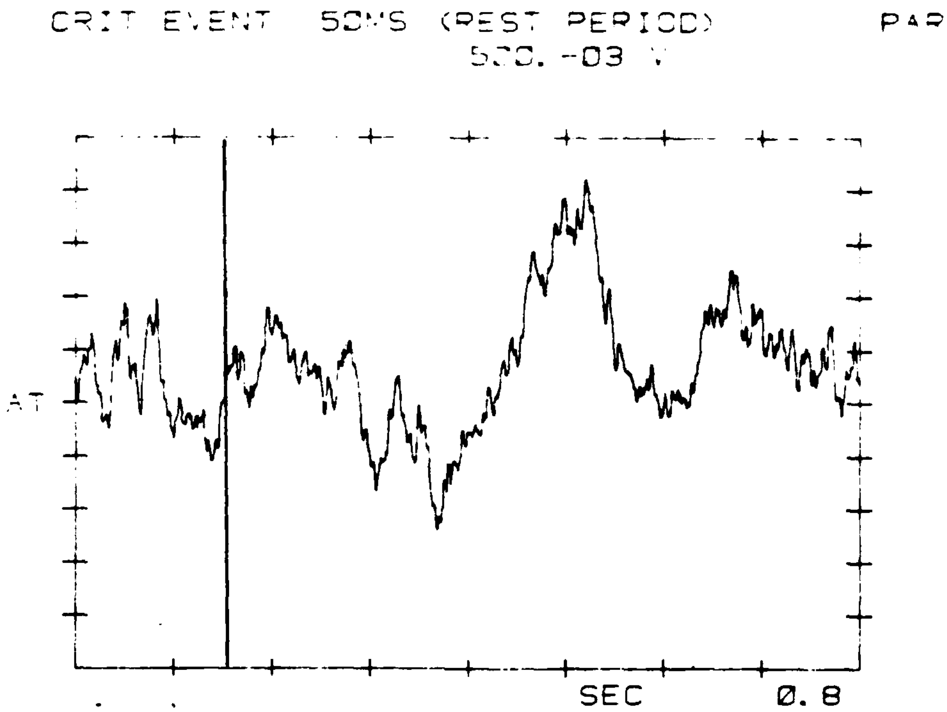


Fig 9. Condition 1/Subject 1



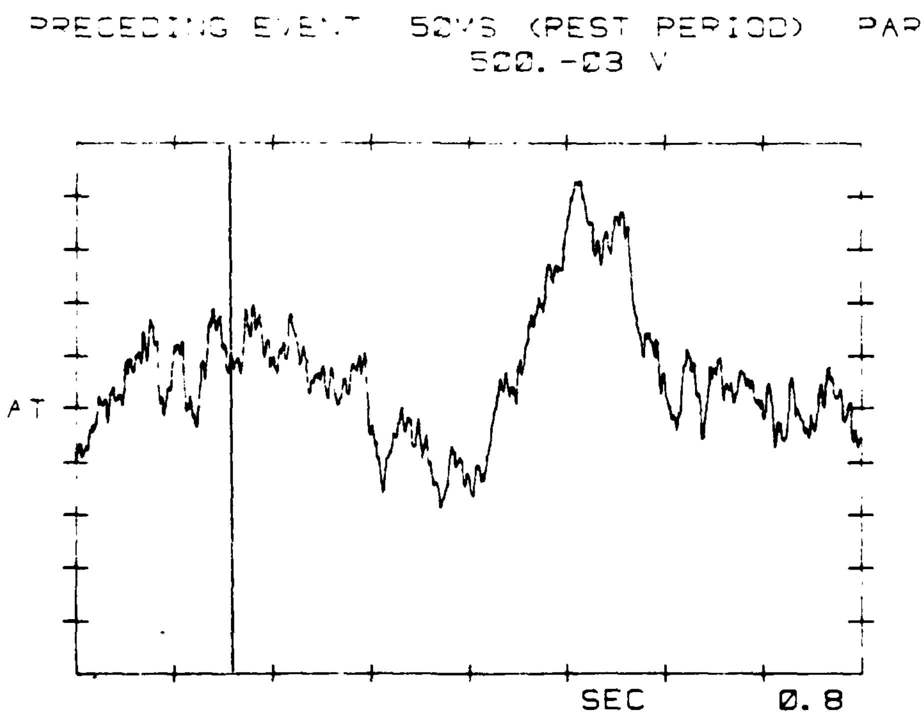
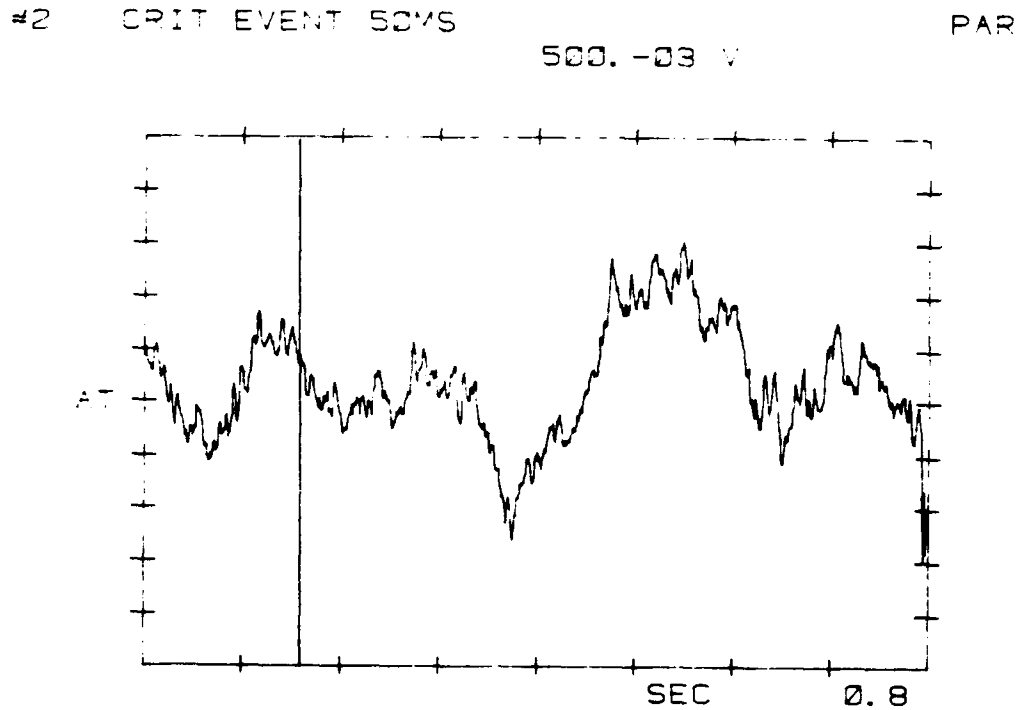


Fig 10. Condition 0/Subject 2



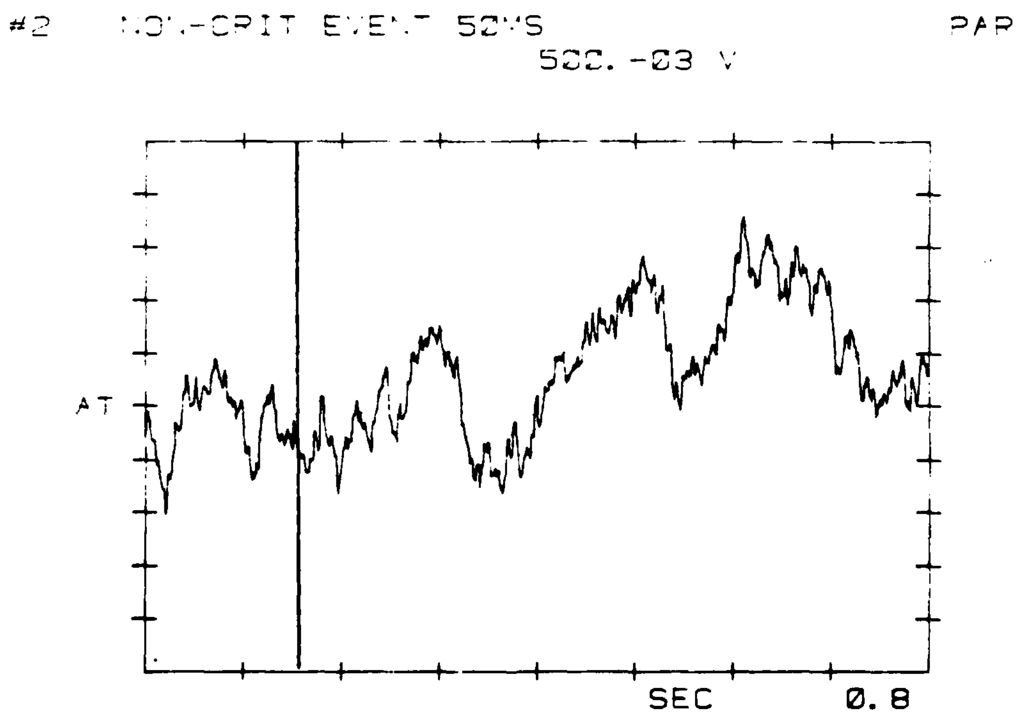
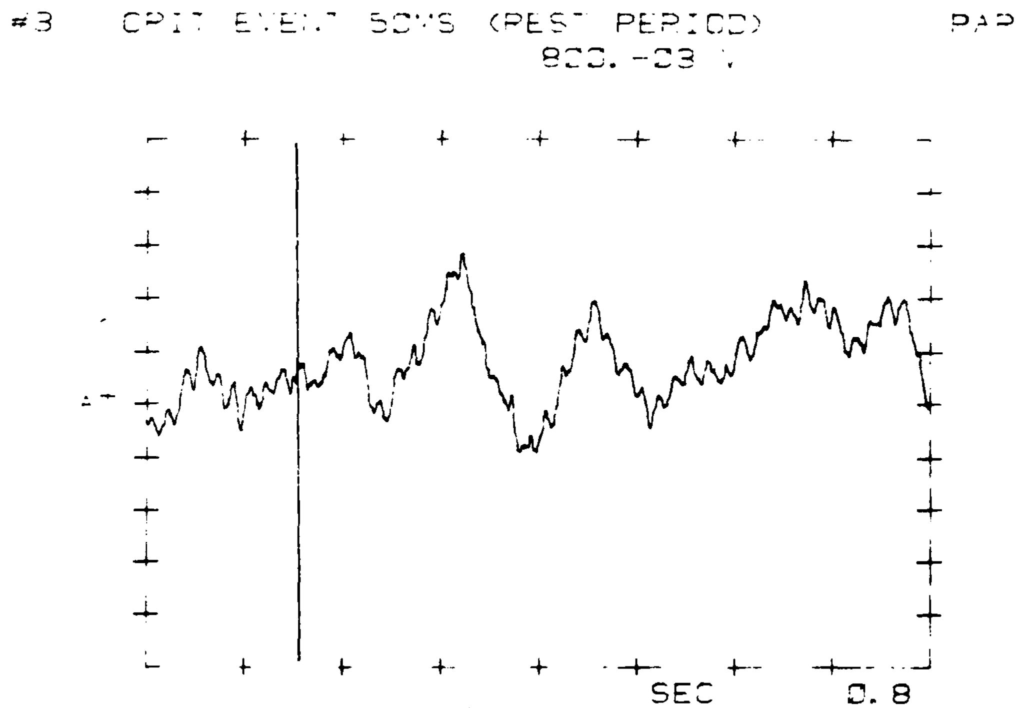


Fig 11. Condition 1/Subject 2



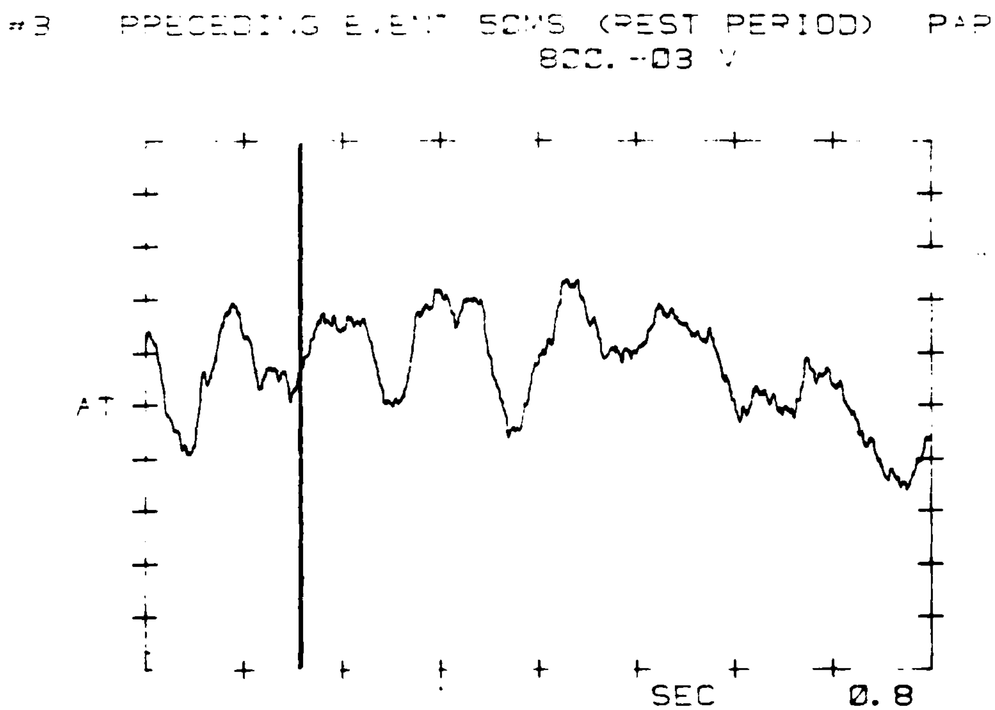
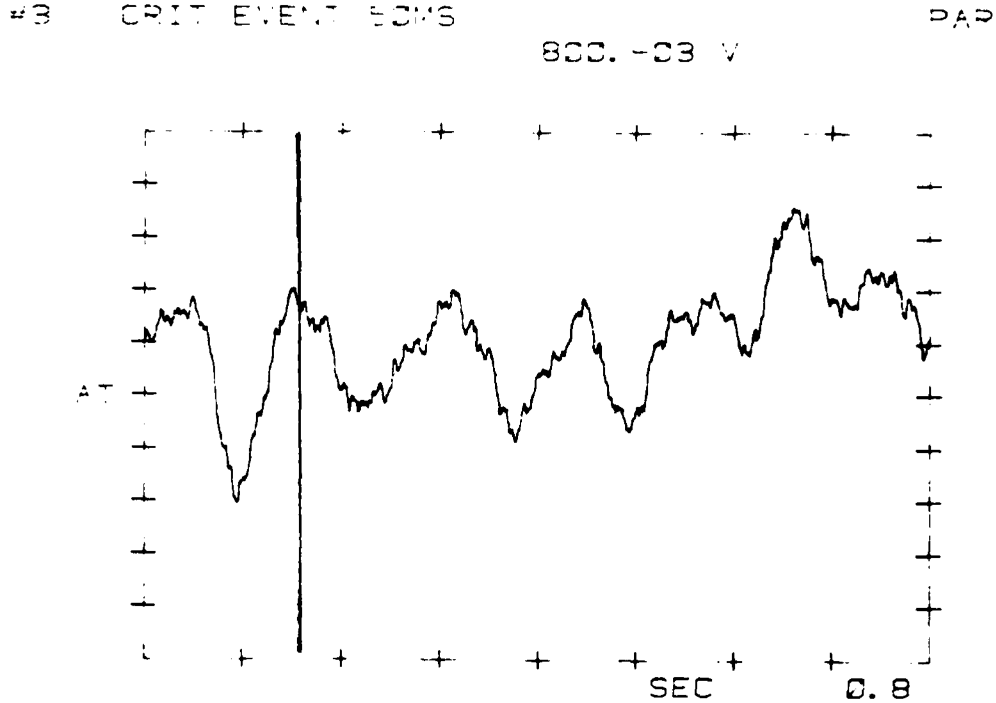


Fig 12. Condition 0/Subject 3



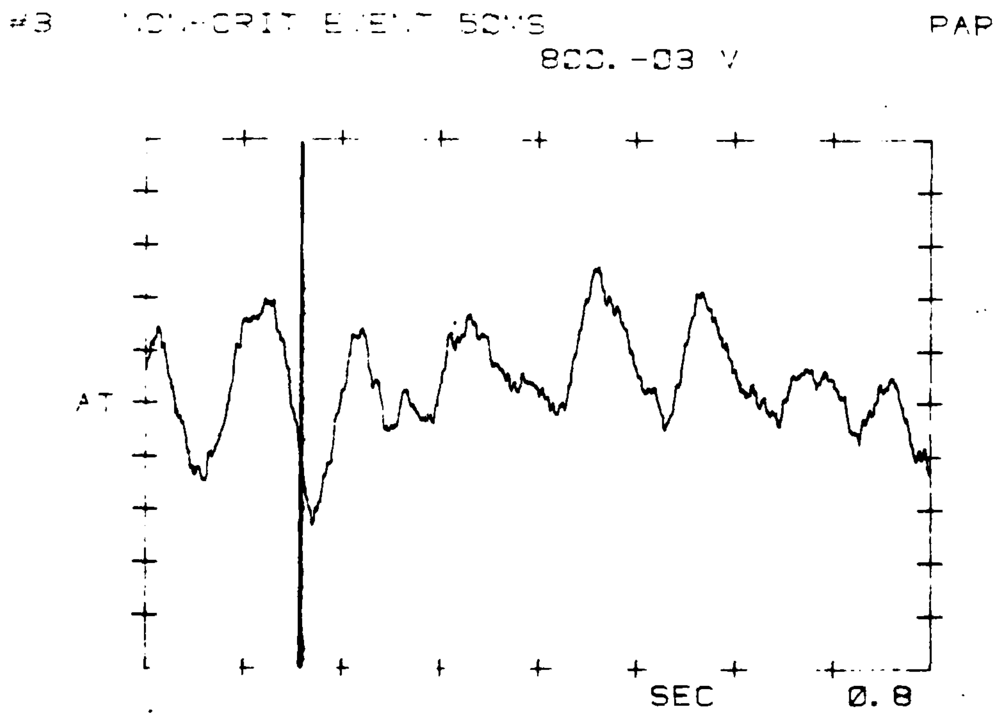
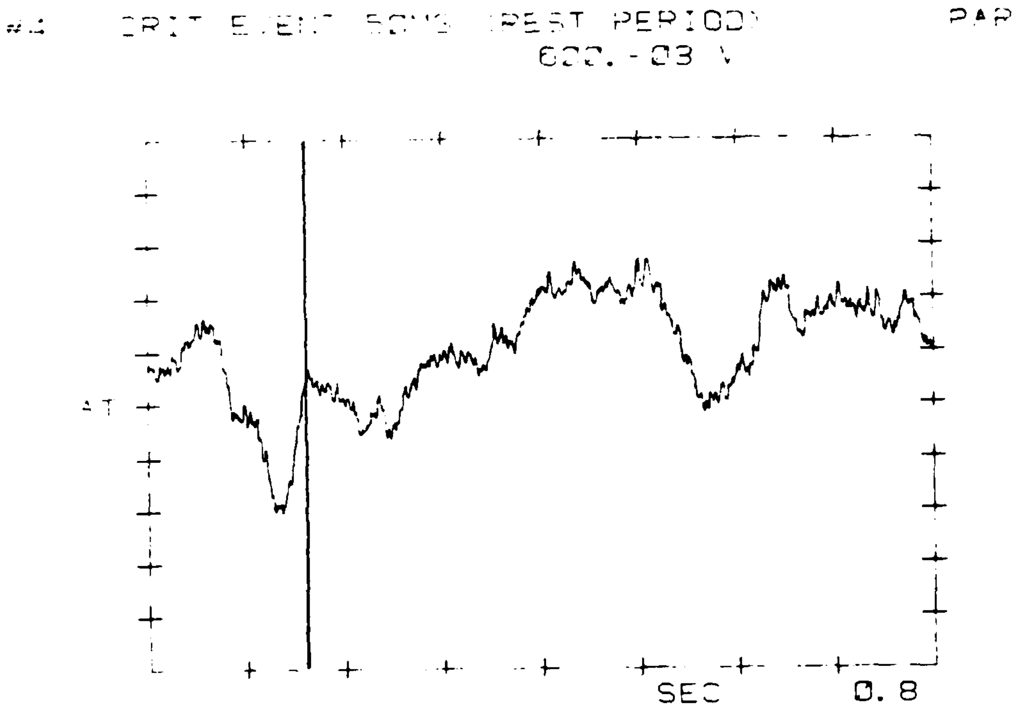


Fig 13. Condition 1/Subject 3



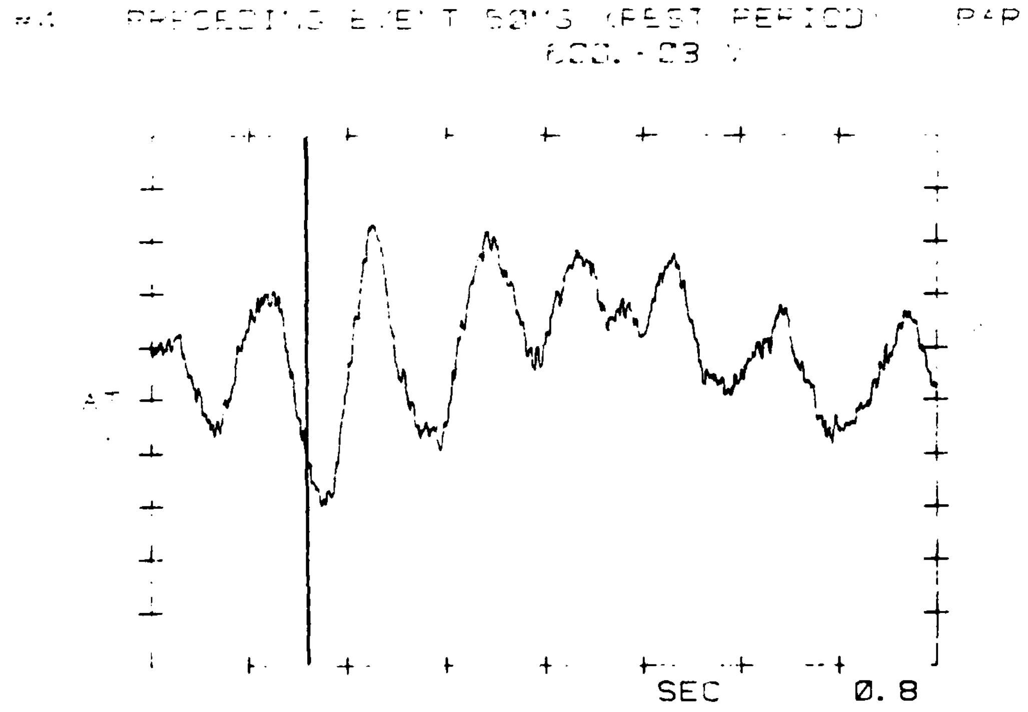
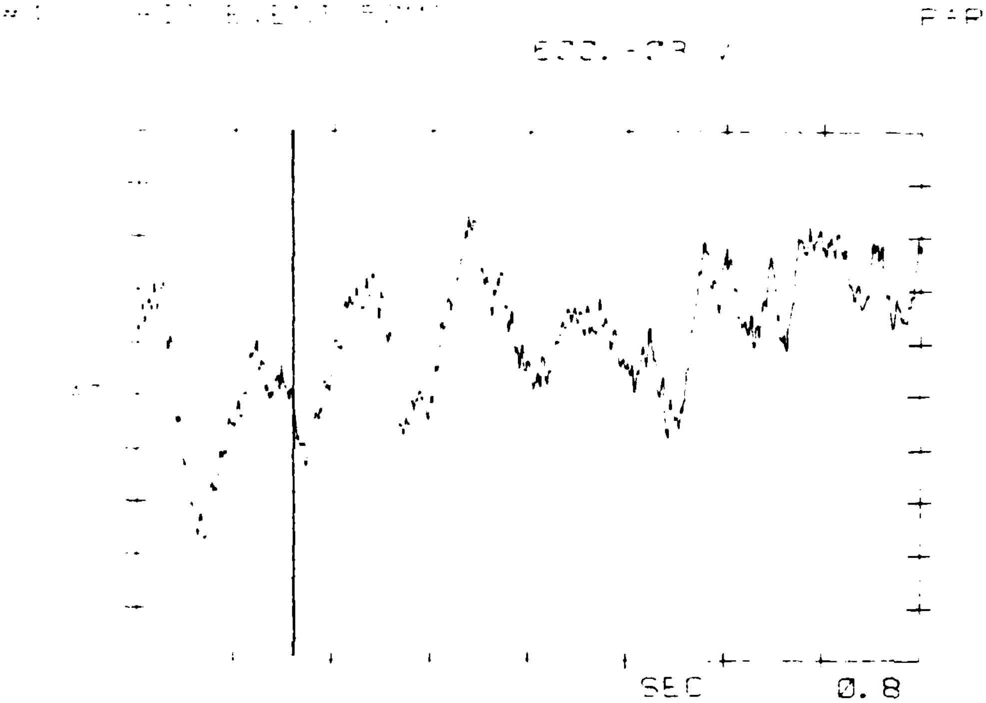


Fig 14. Condition 0/Subject 4



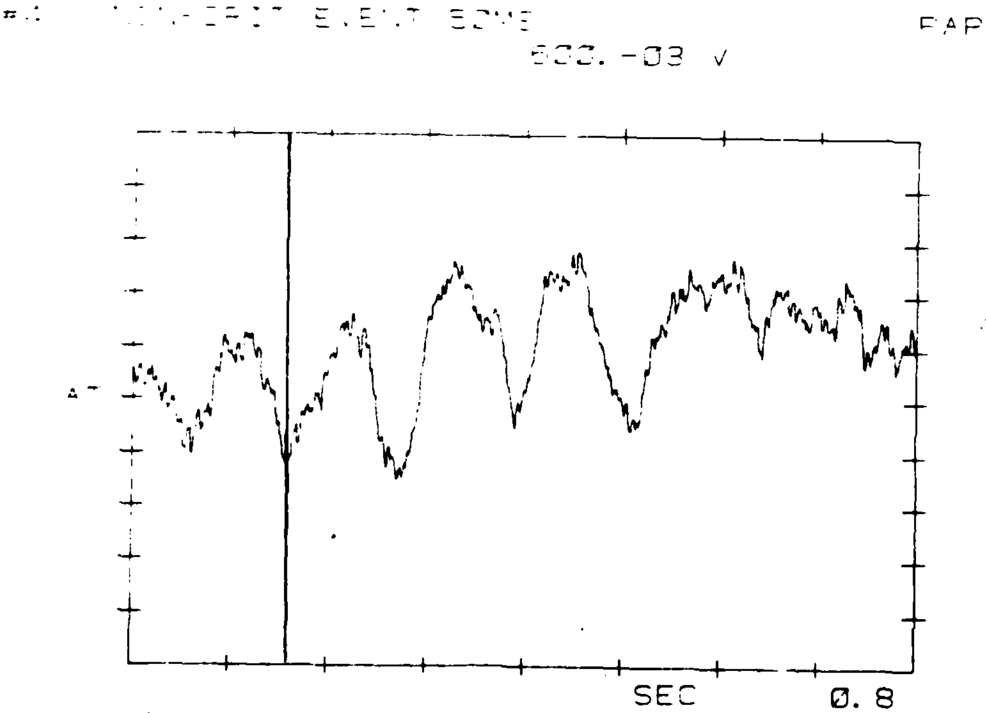
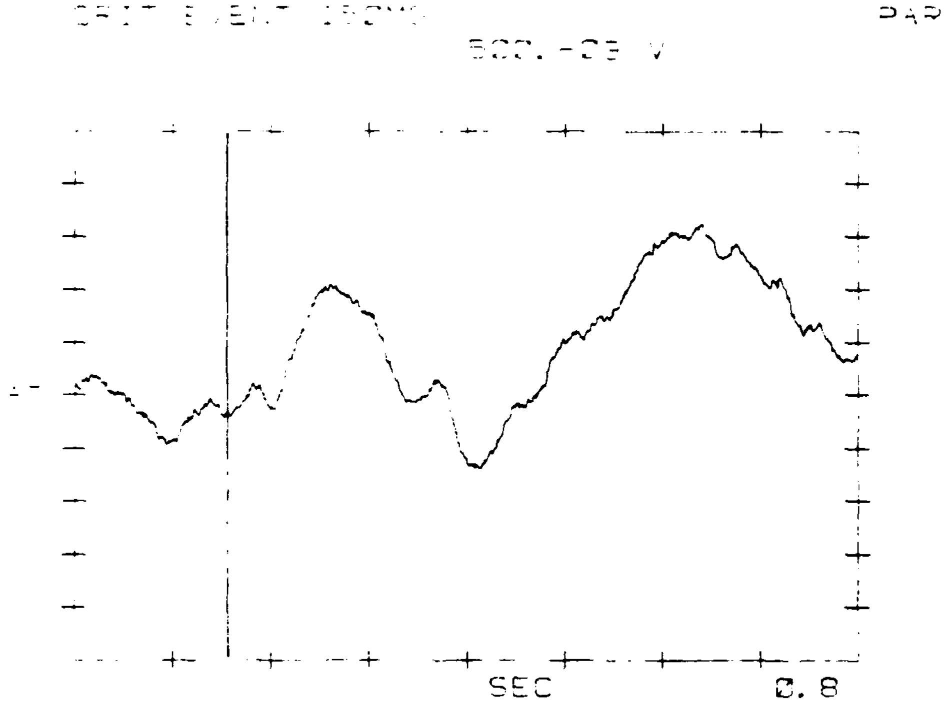


Fig 15. Condition 1/Subject 4



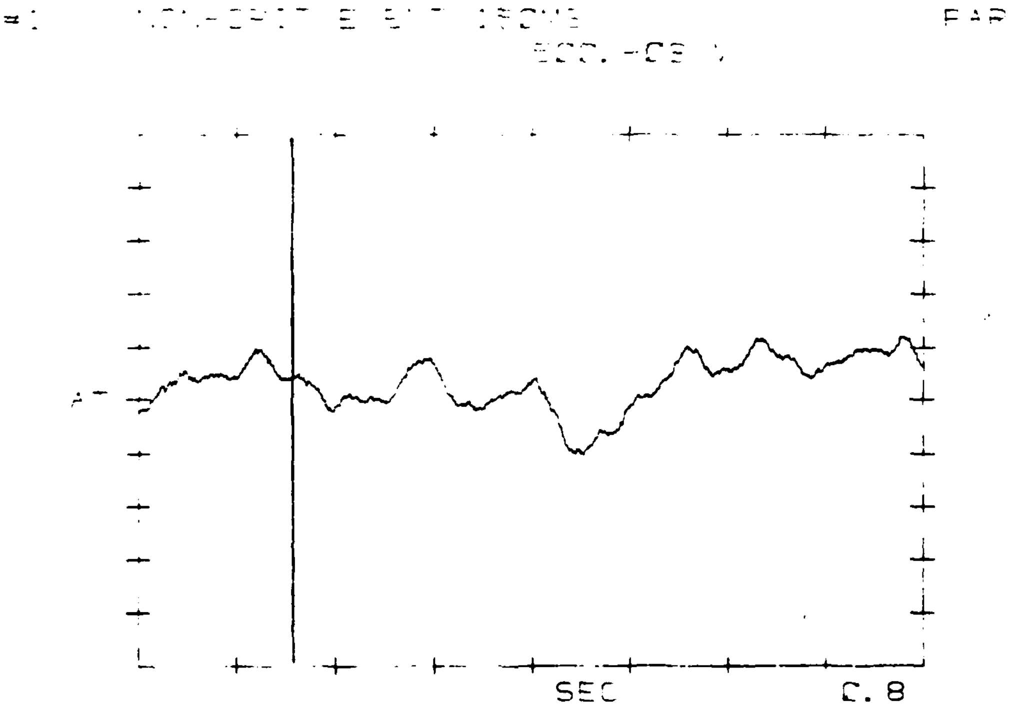


Fig 16. Condition 2/Subject 1

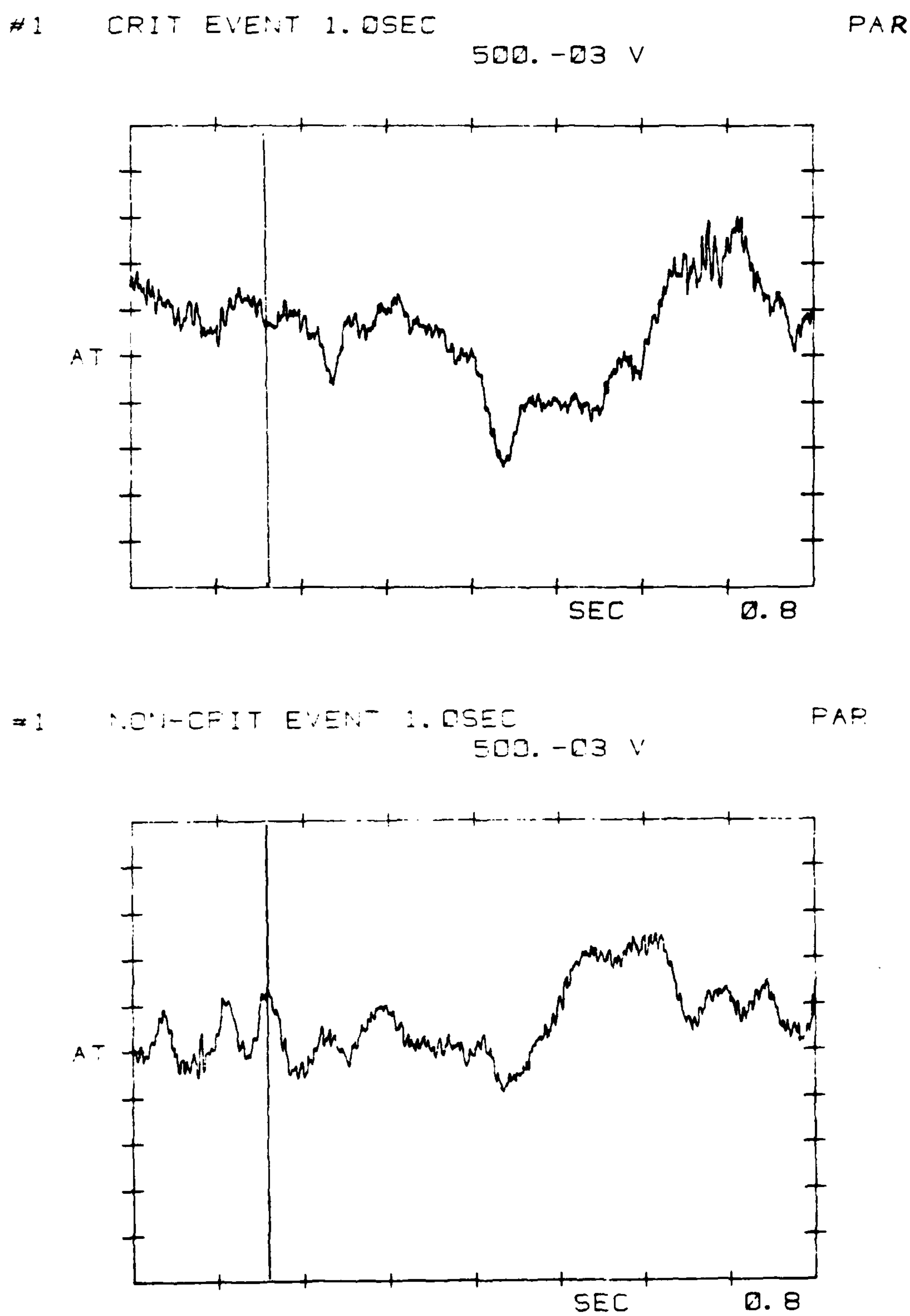


Fig 17. Condition 3/Subject 1

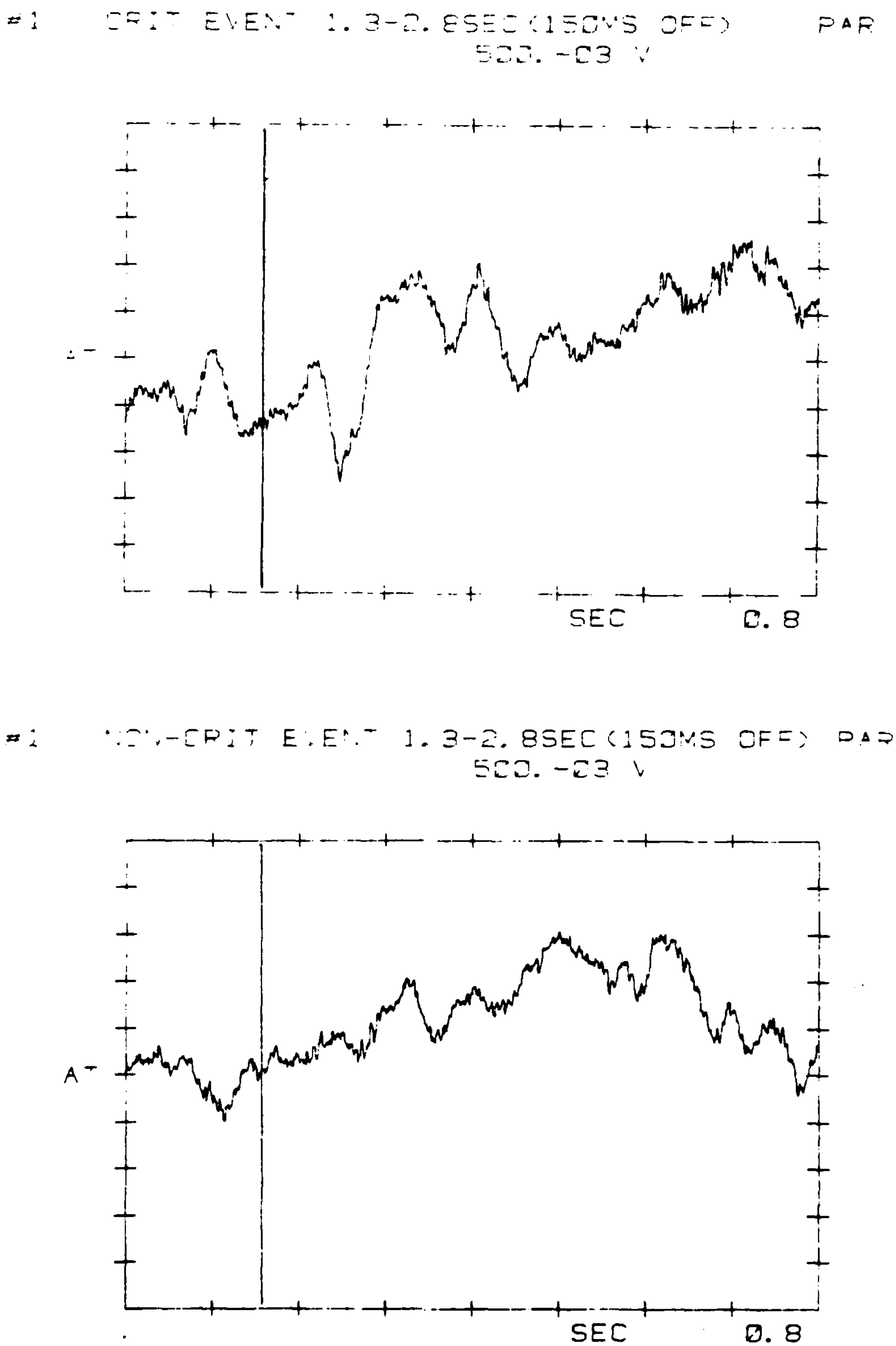
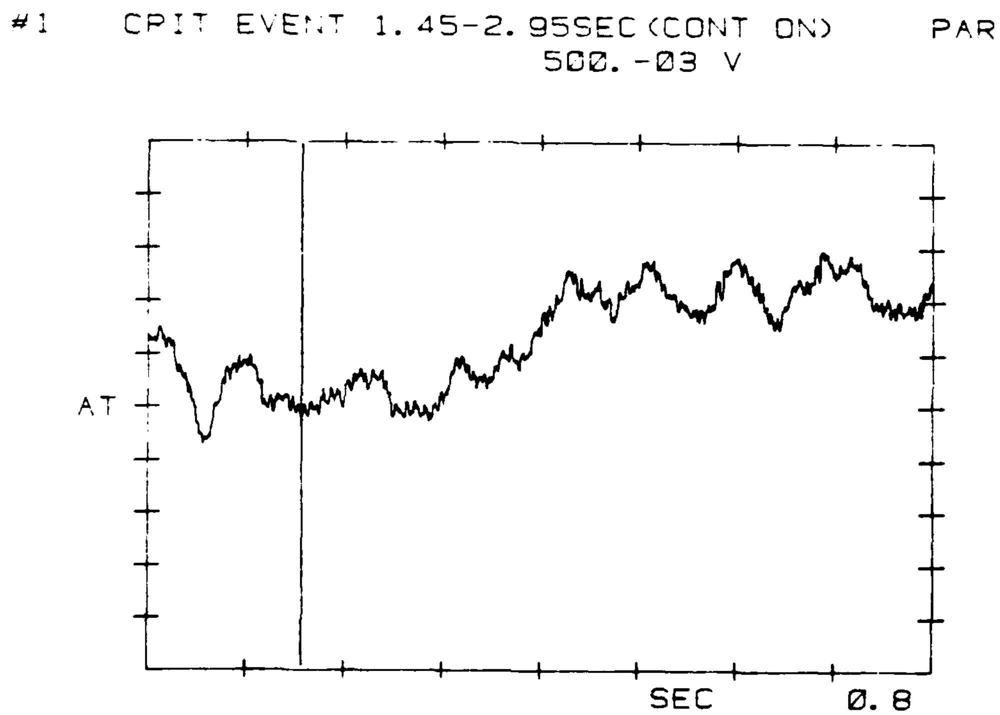


Fig 18. Condition 4/Subject 1



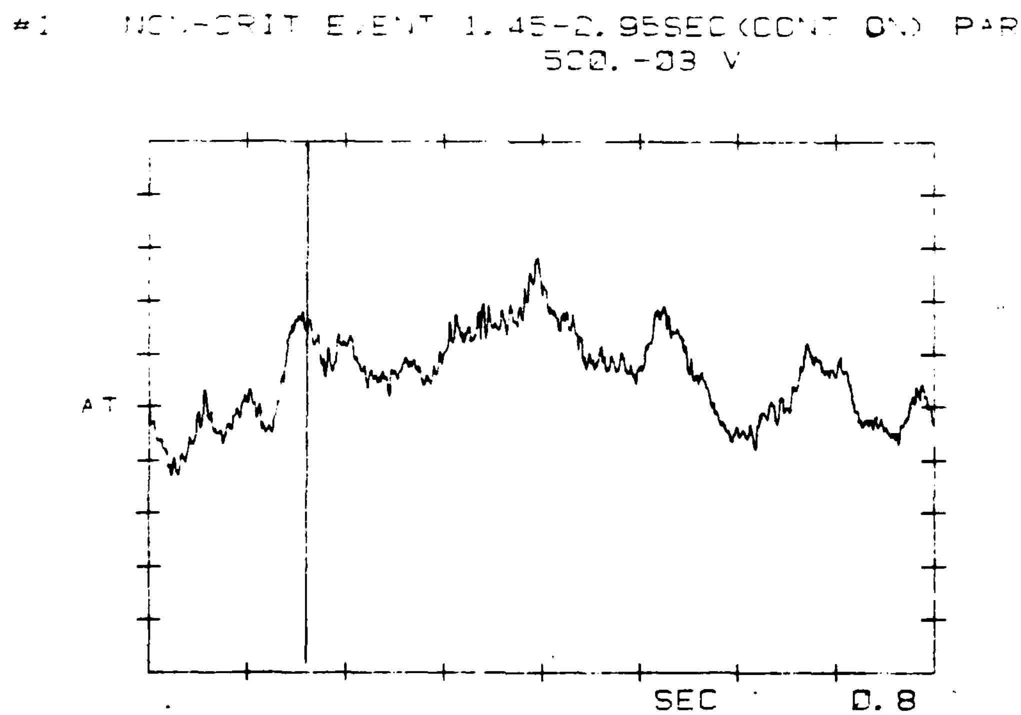
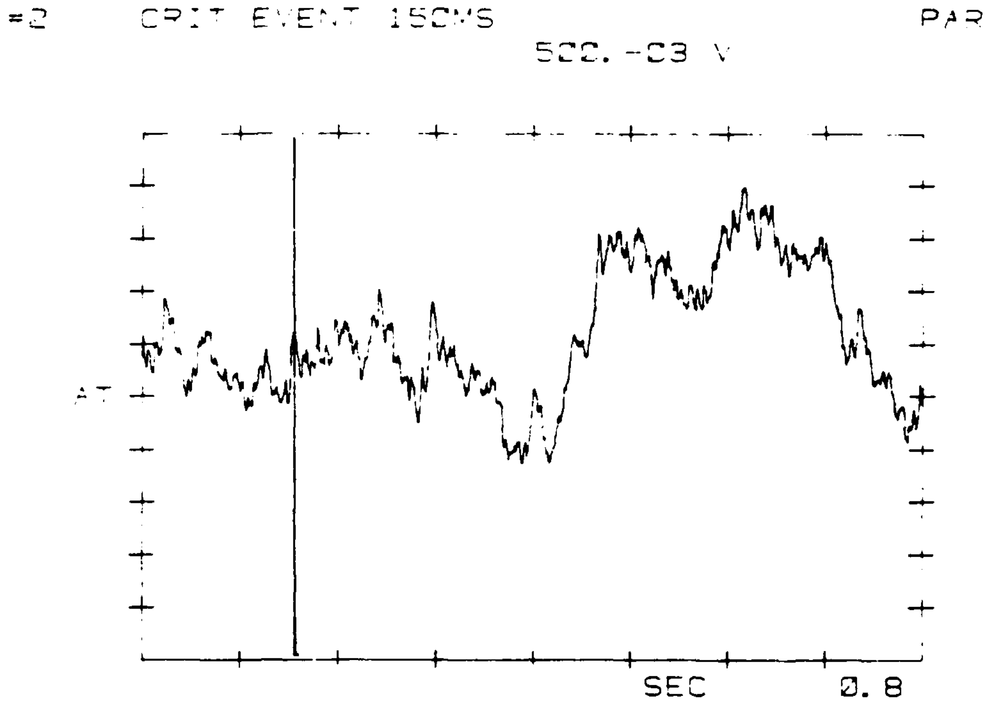


Fig 19. Condition 5/Subject 1



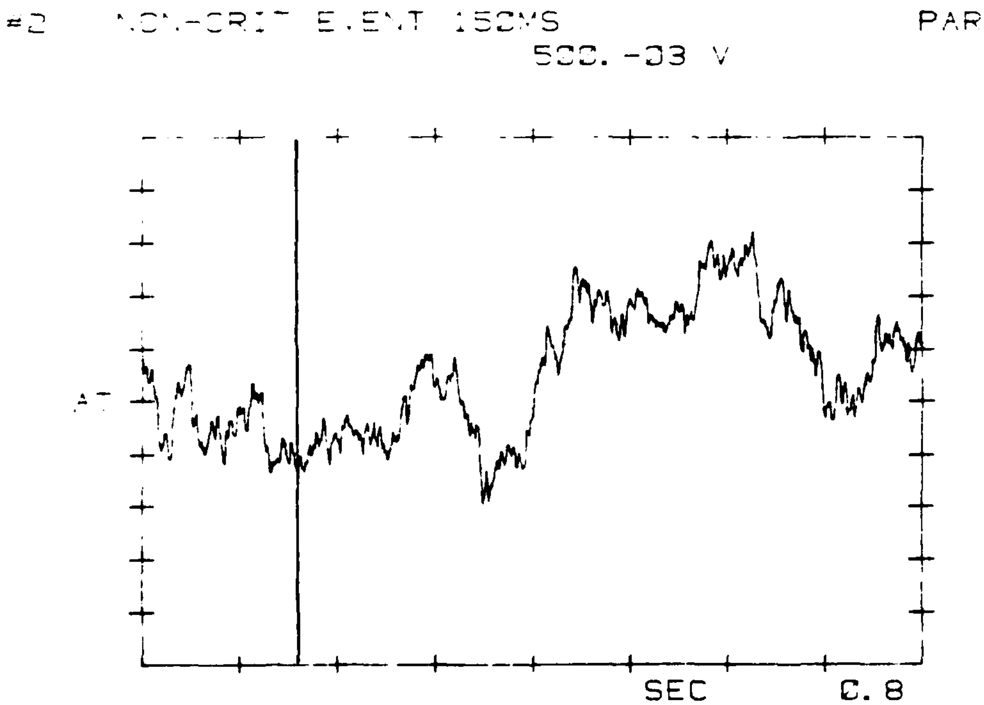
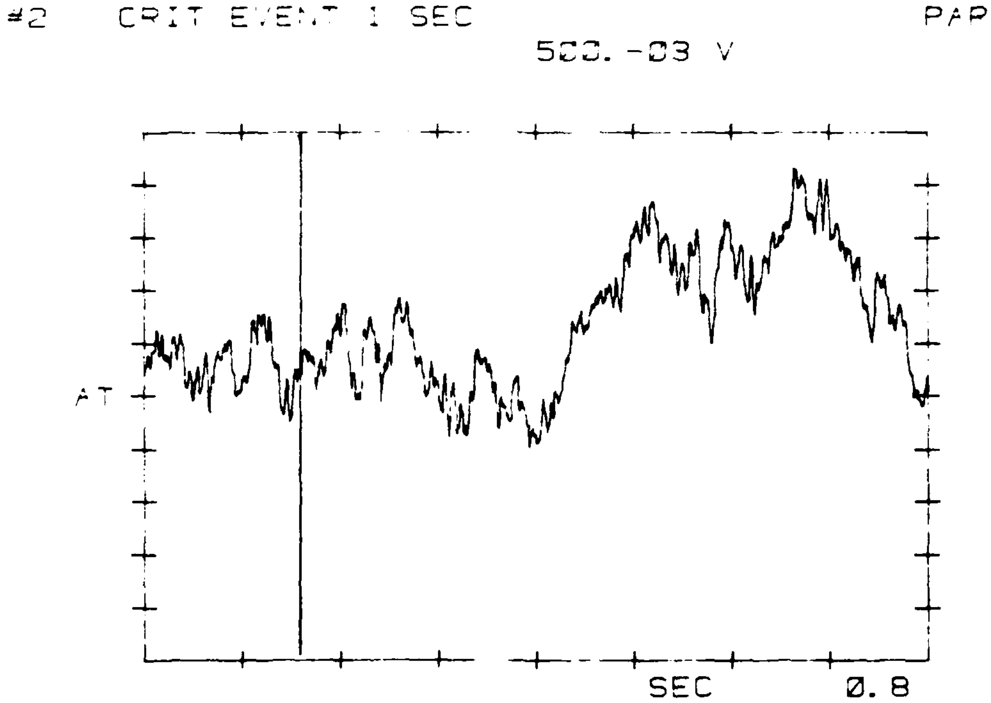


Fig 20. Condition 2/Subject 2



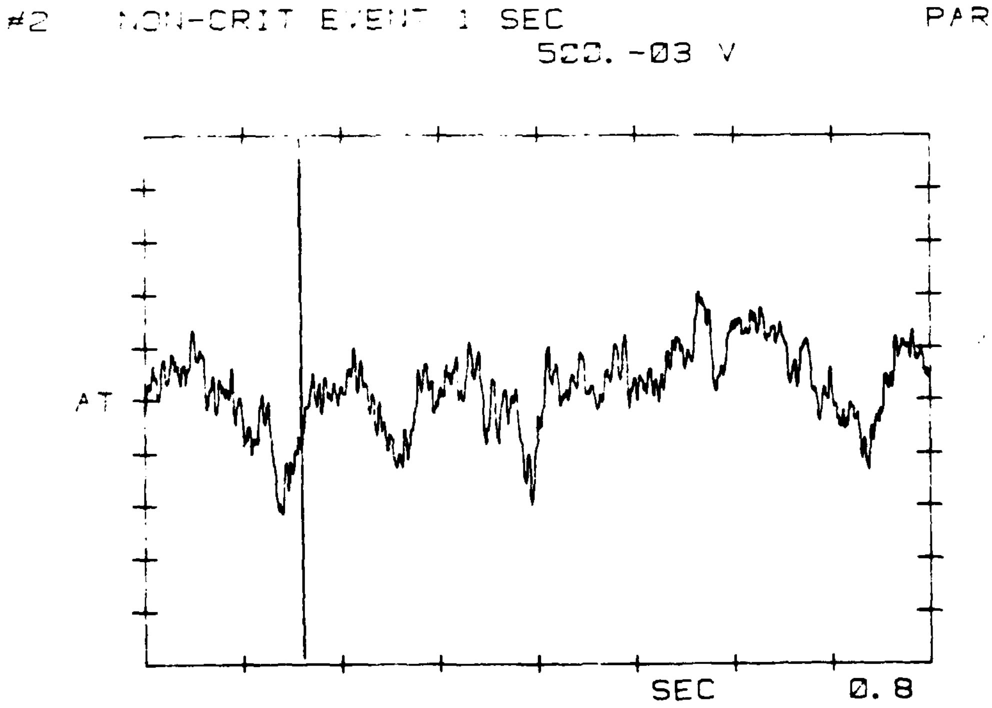
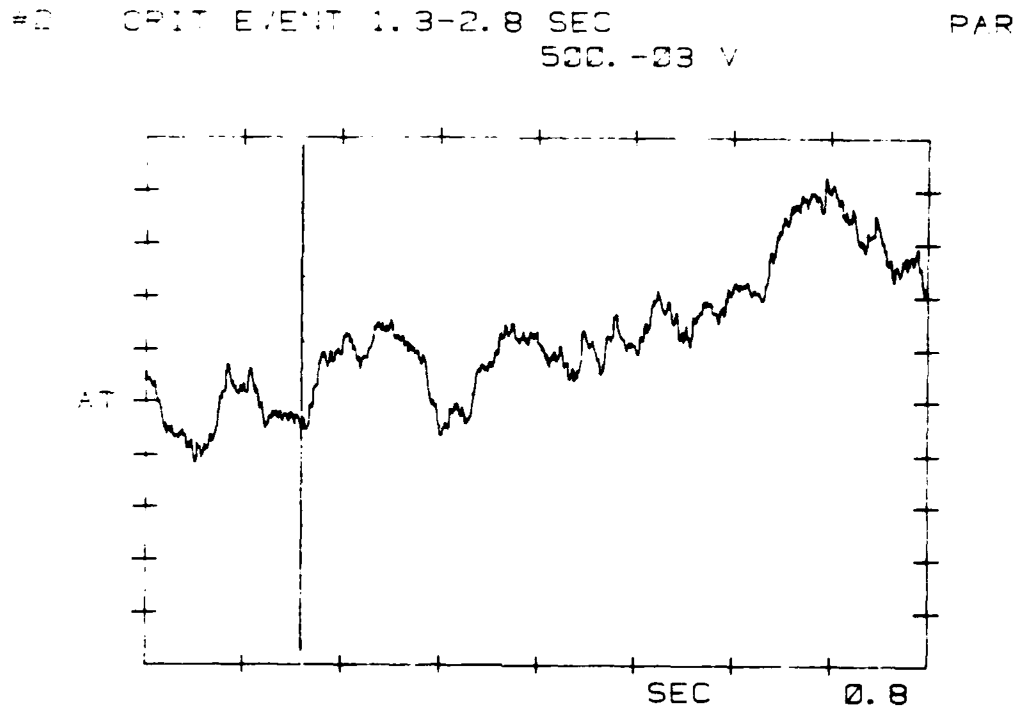


Fig 21. Condition 3/Subject 2



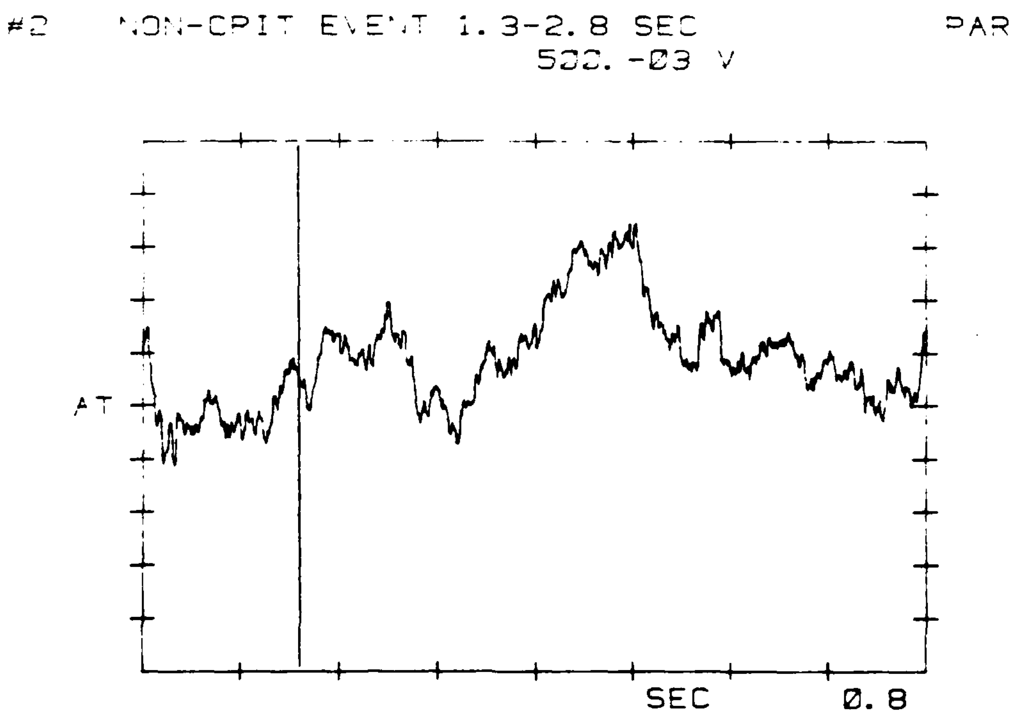
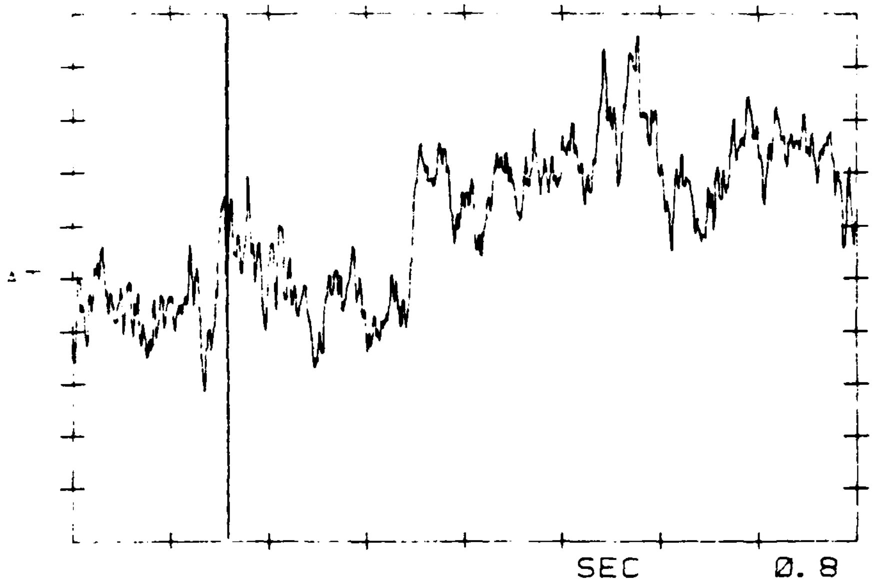


Fig 22. Condition 4/Subject 2

#2 CRIT EVENT 1.45-2.95 SEC (CONT ON) PAR
500.-03 V



#2 NON-CRIT EVENT 1.45-2.95 S (CONT ON) PAR
500.-03 V

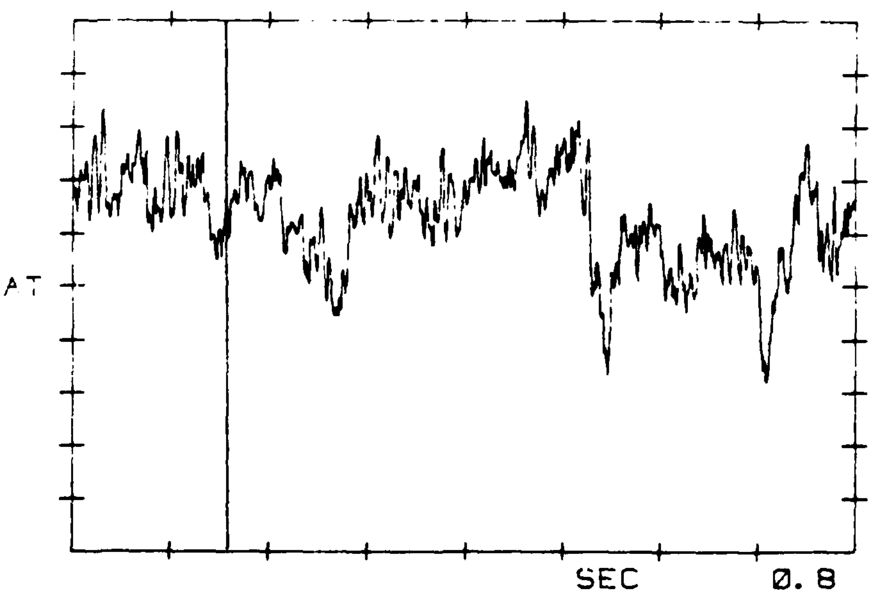


Fig 23. Condition 5/Subject 2

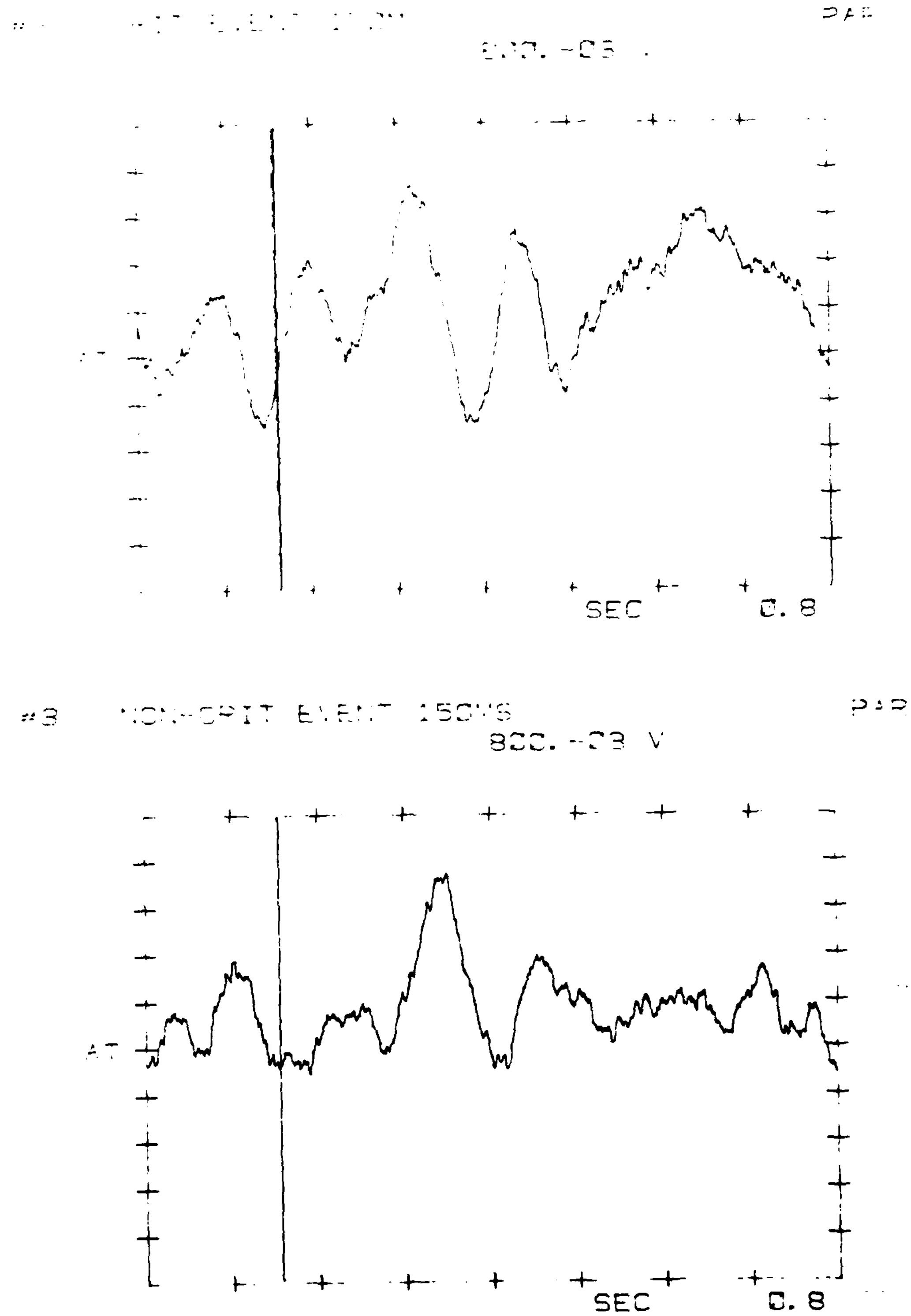
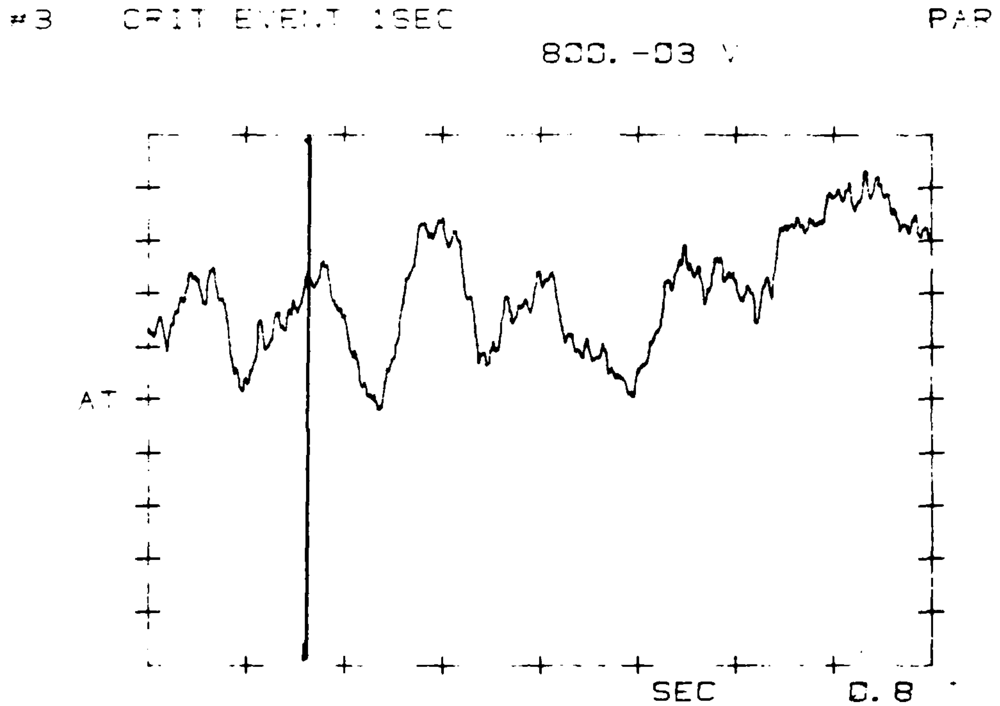


Fig 24. Condition 2/Subject 3



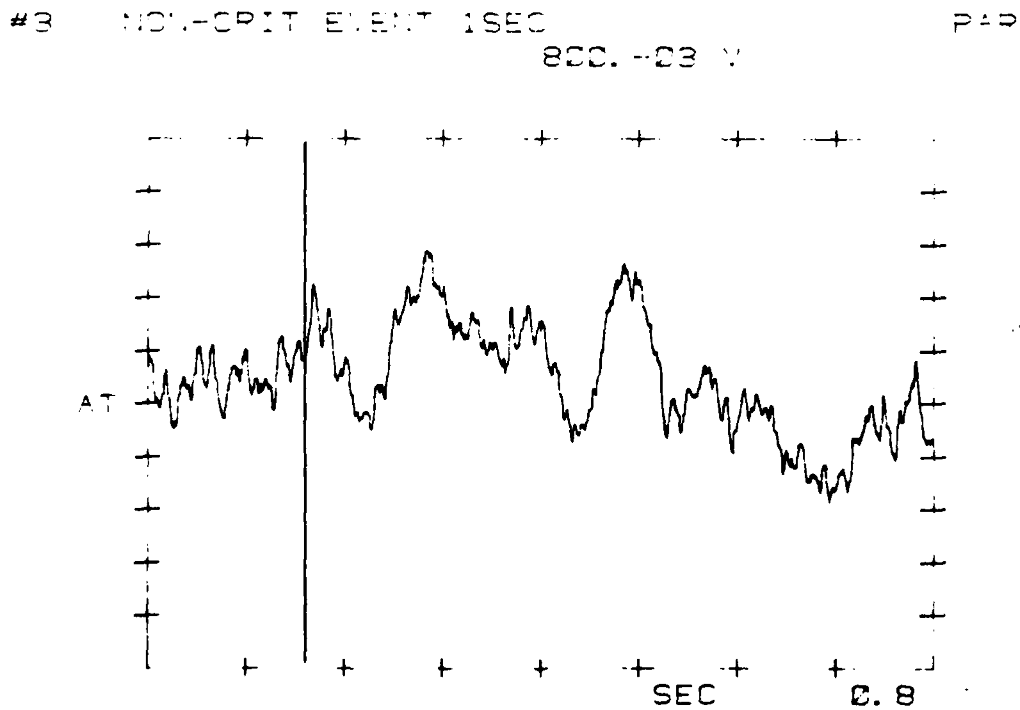
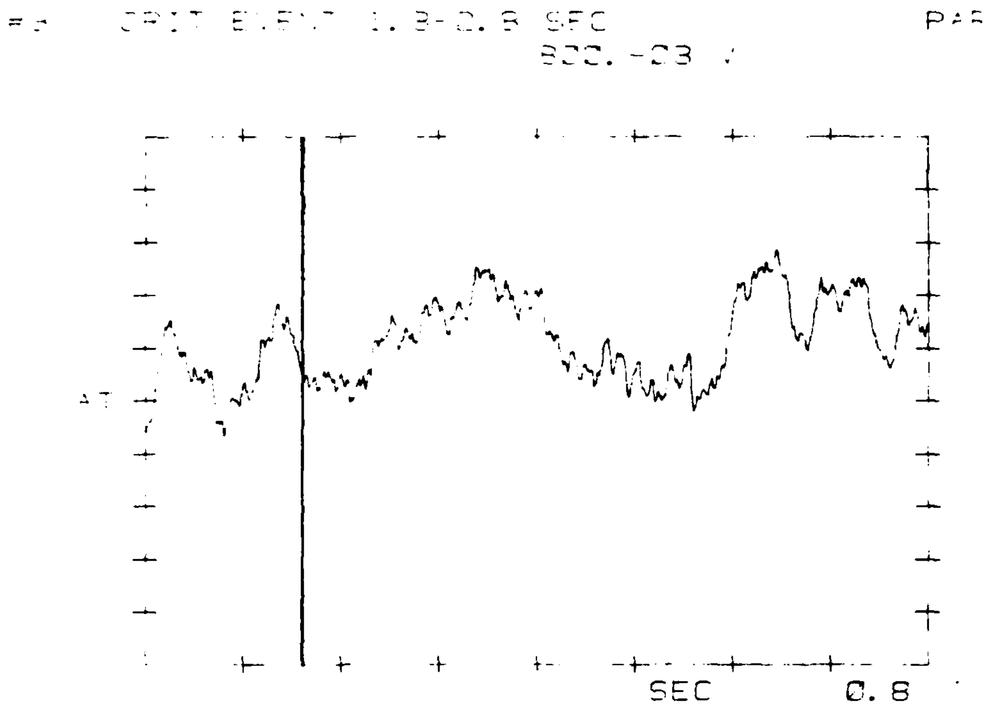


Fig 25. Condition 3/Subject 3



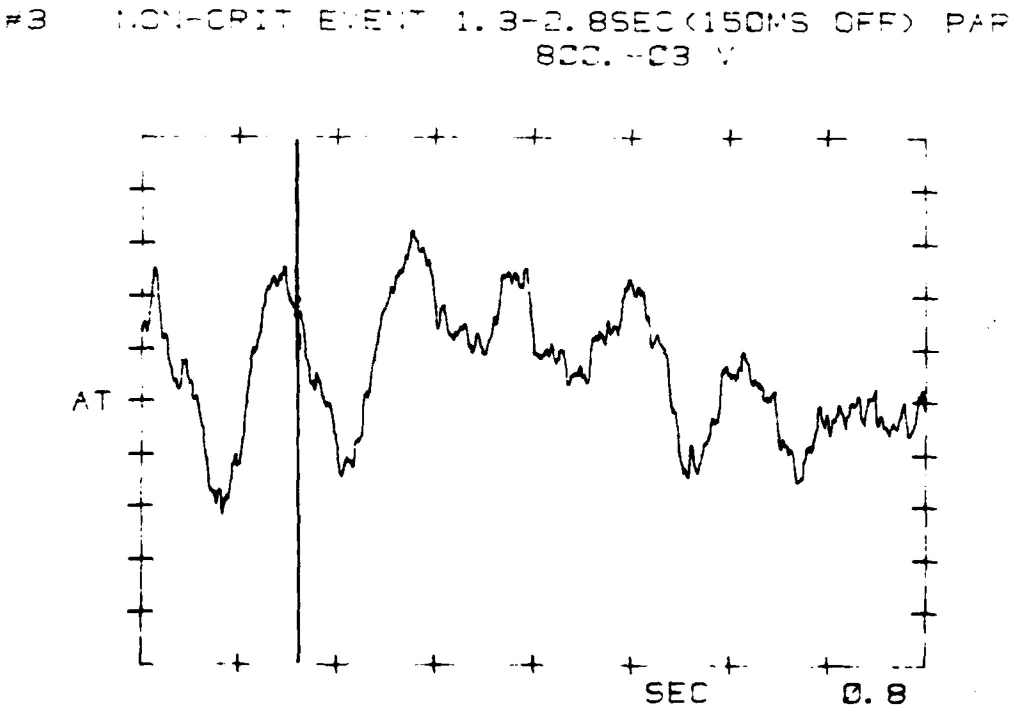
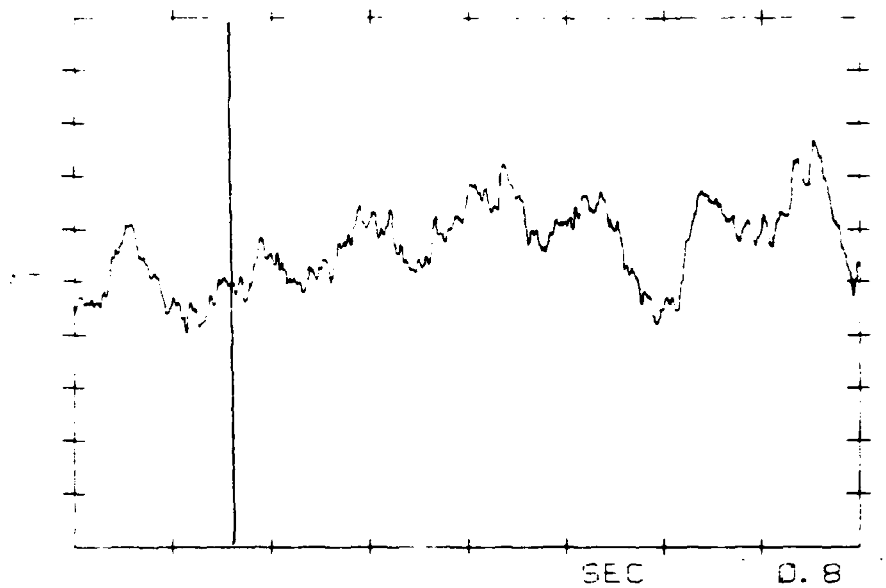


Fig 26. Condition 4/Subject 3



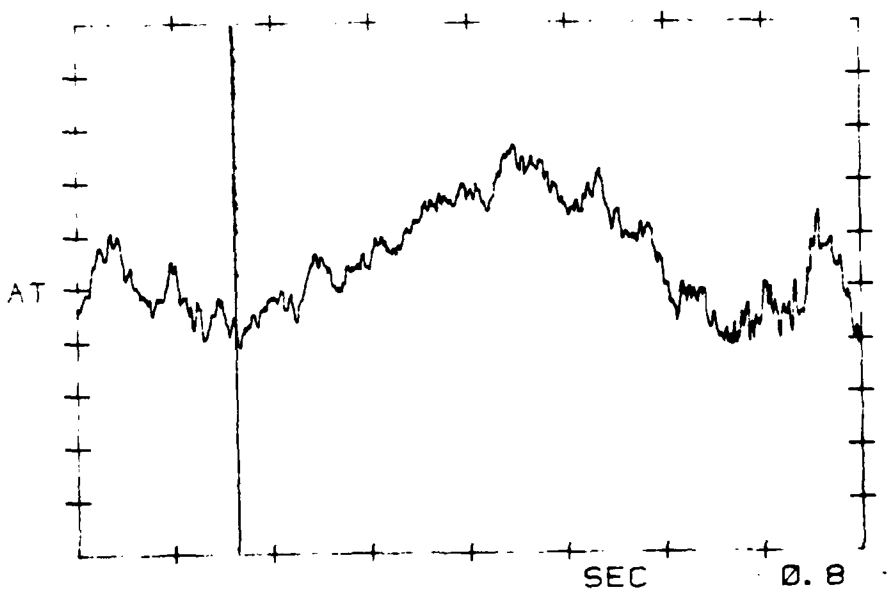


Fig 27. Condition 5/Subject 3

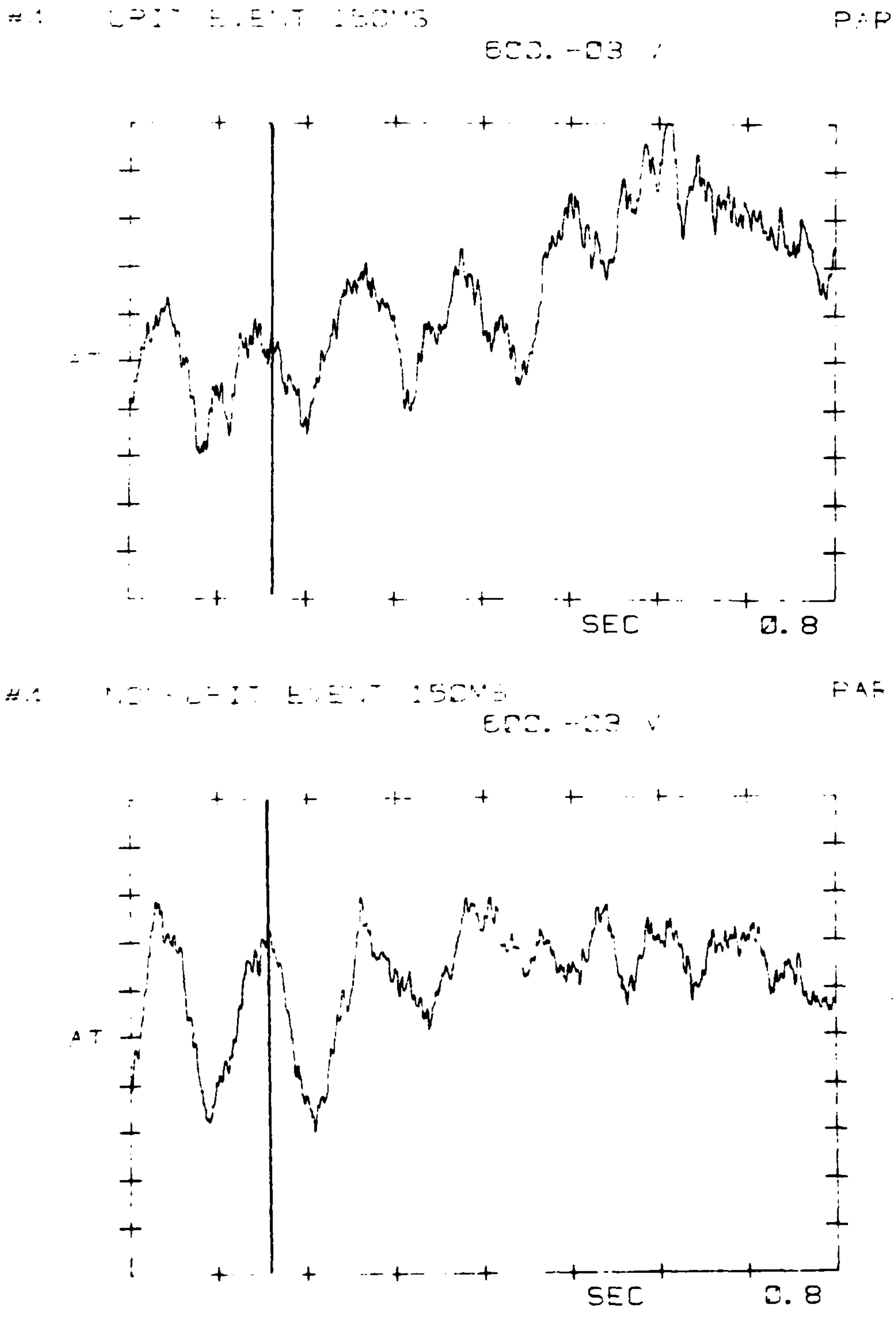
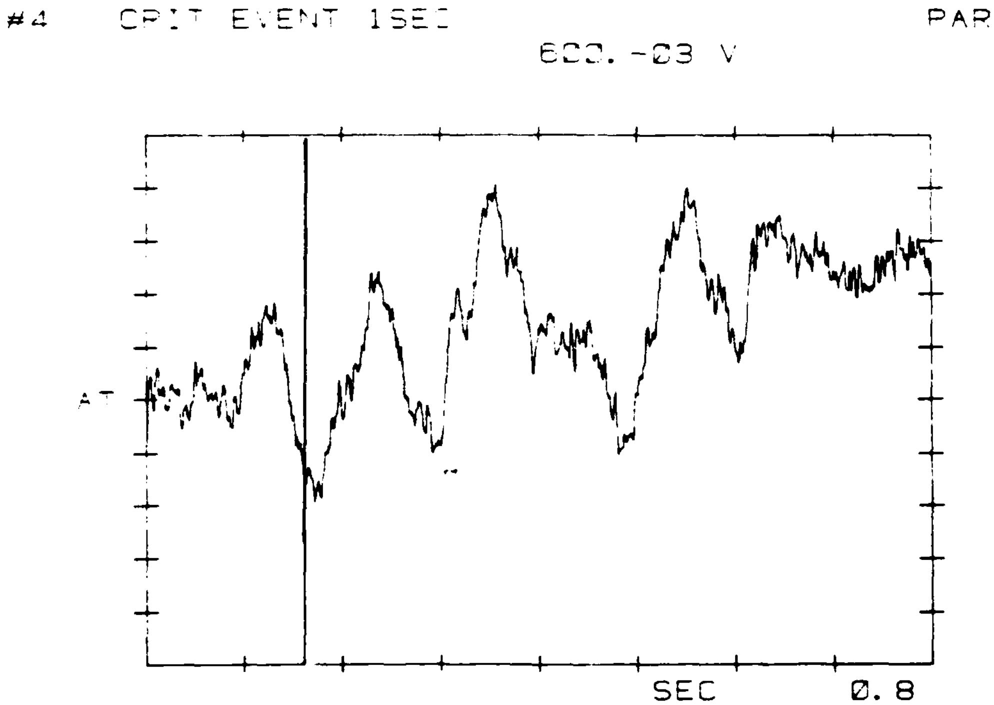


Fig 28. Condition 2/Subject 4



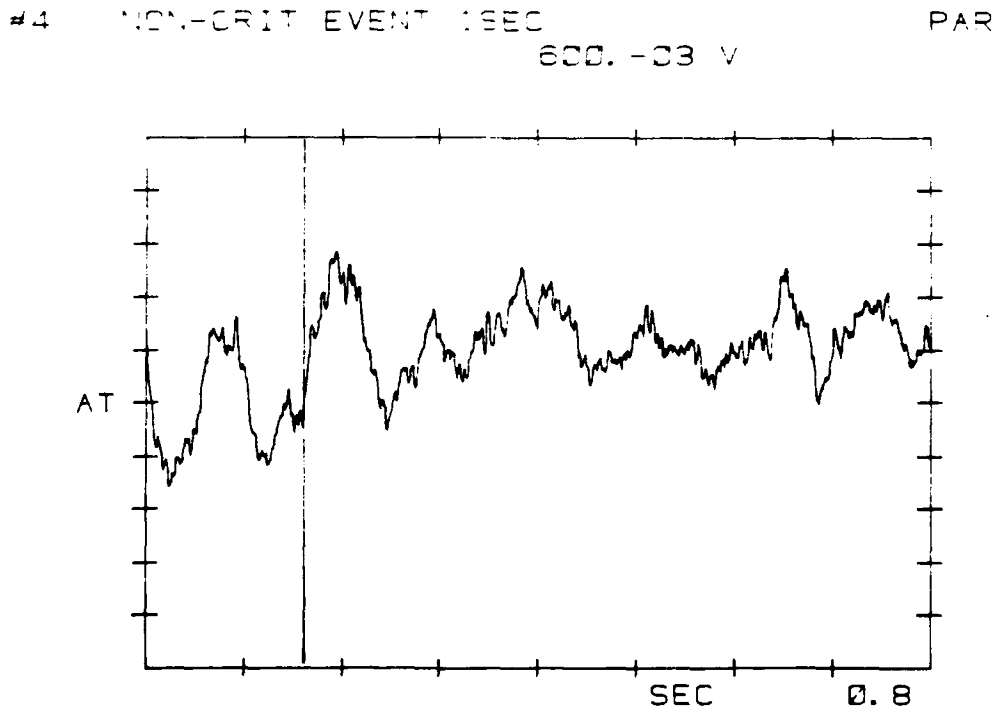
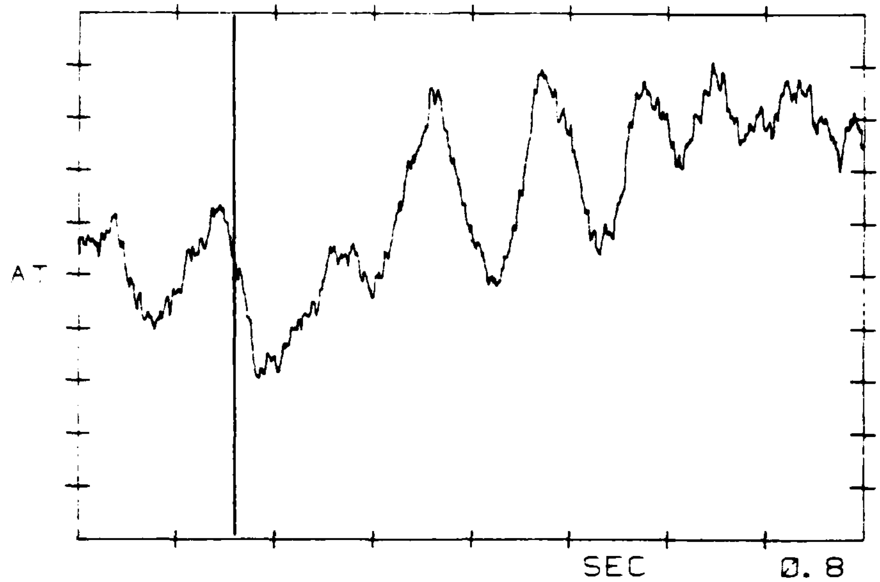


Fig 29. Condition 3/Subject 4

#4 CRIT EVENT 1.3-2.8SEC(150MS OFF) PAR
600. -C3 V



#4 NON- CRIT EVENT 1.3-2.8SEC(15ØMS OFF) PAR
600. -C3 V

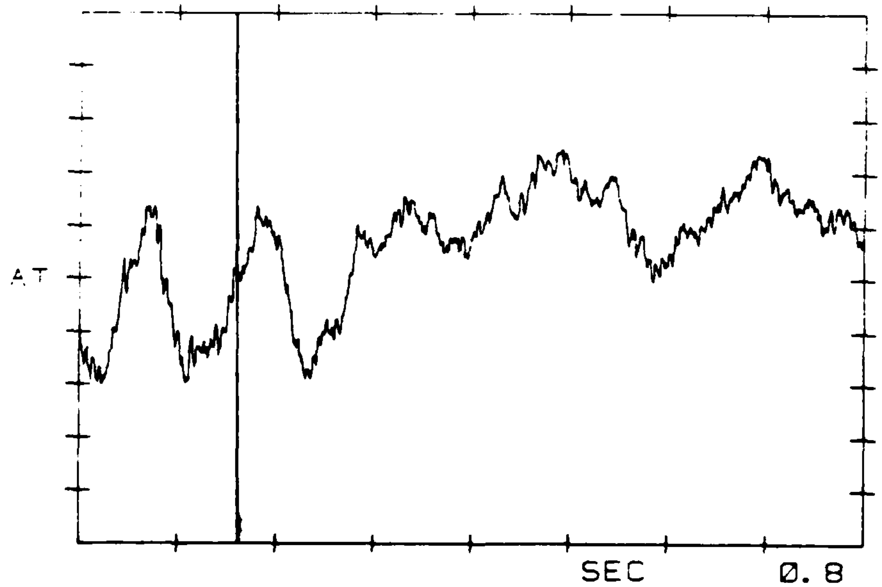
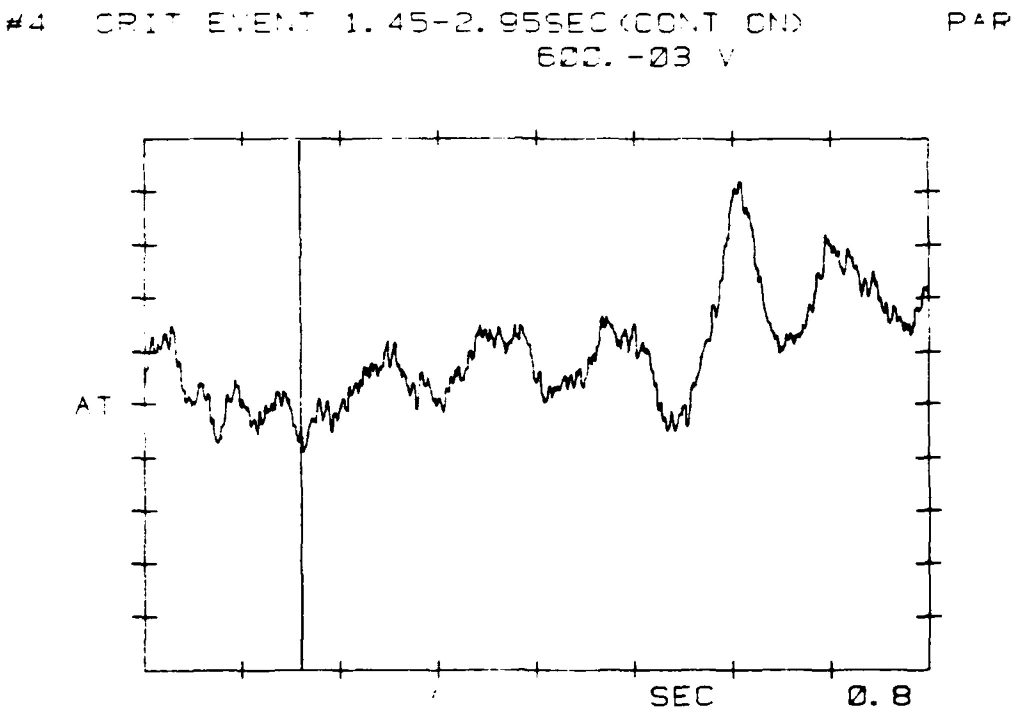


Fig 30. Condition 4/Subject 4



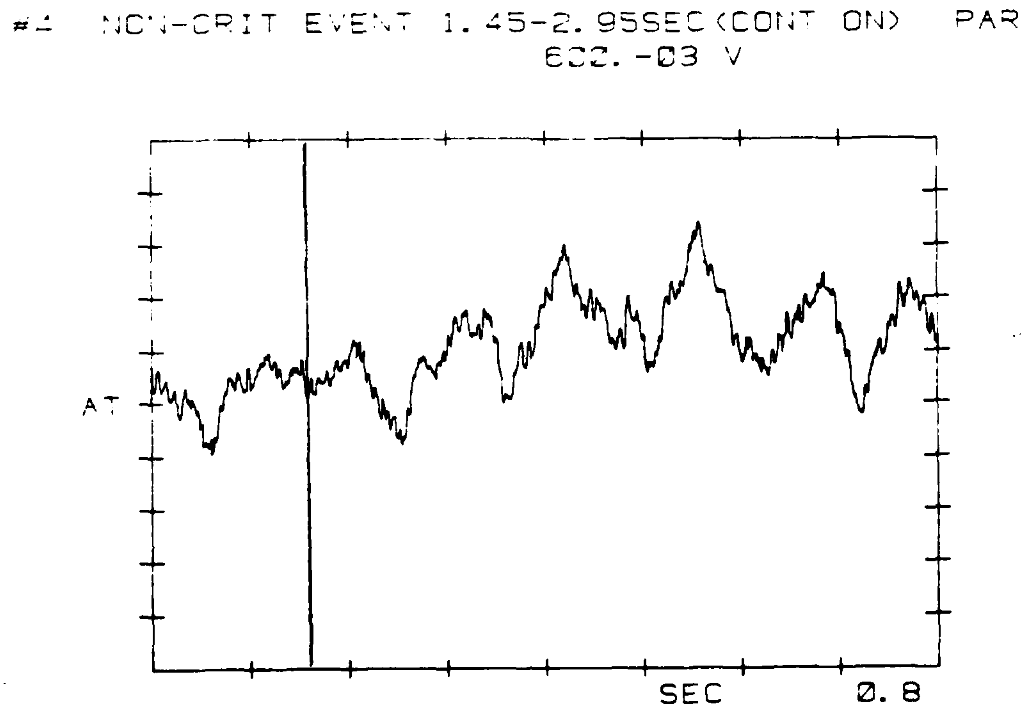
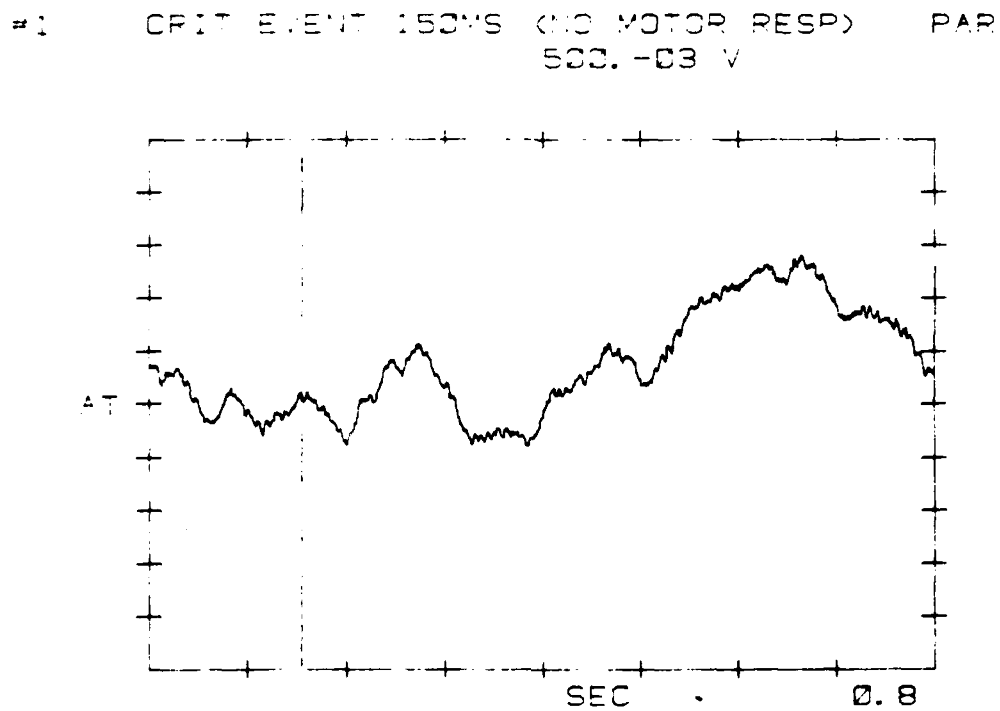


Fig 31. Condition 5/Subject 4



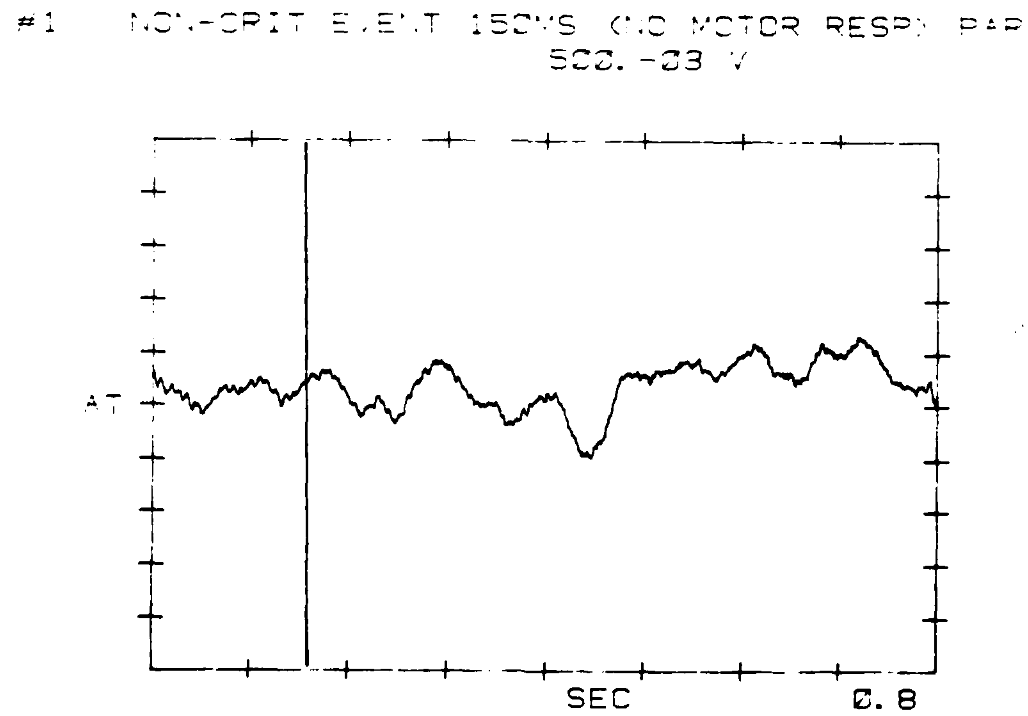


Fig 32. Condition 12/Subject 1

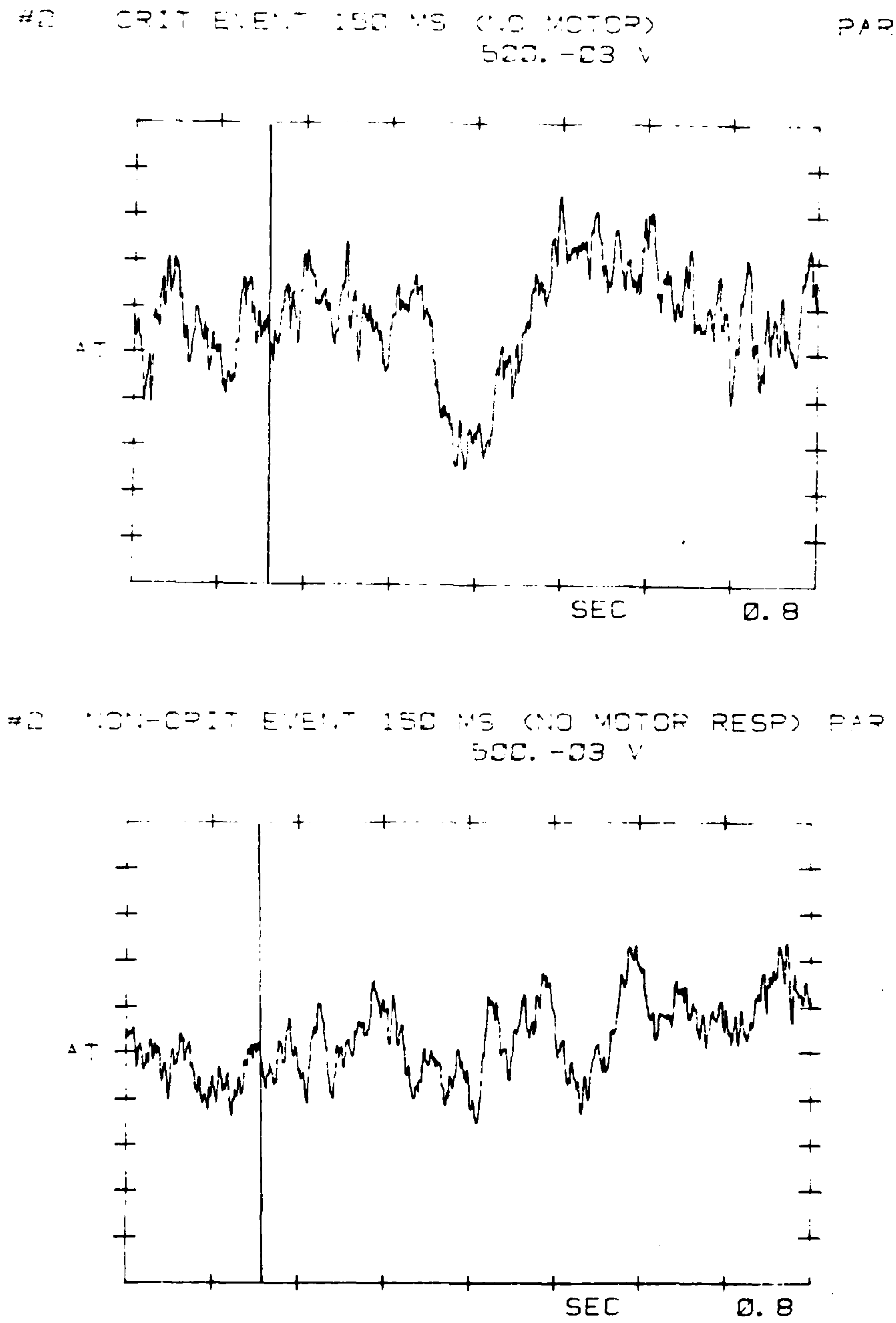
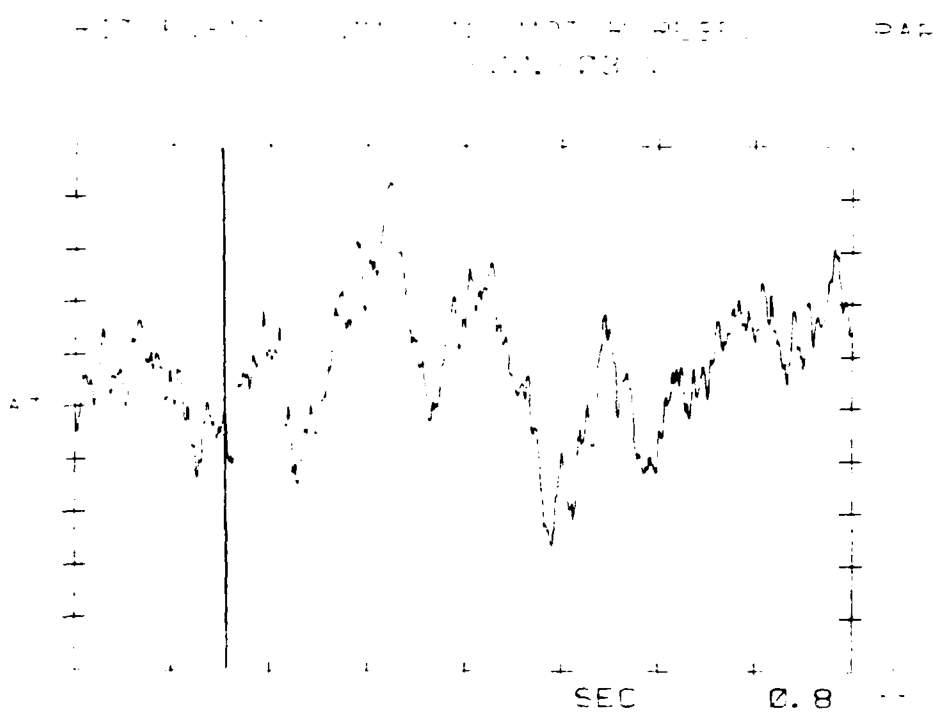


Fig 33. Condition 12/Subject 2



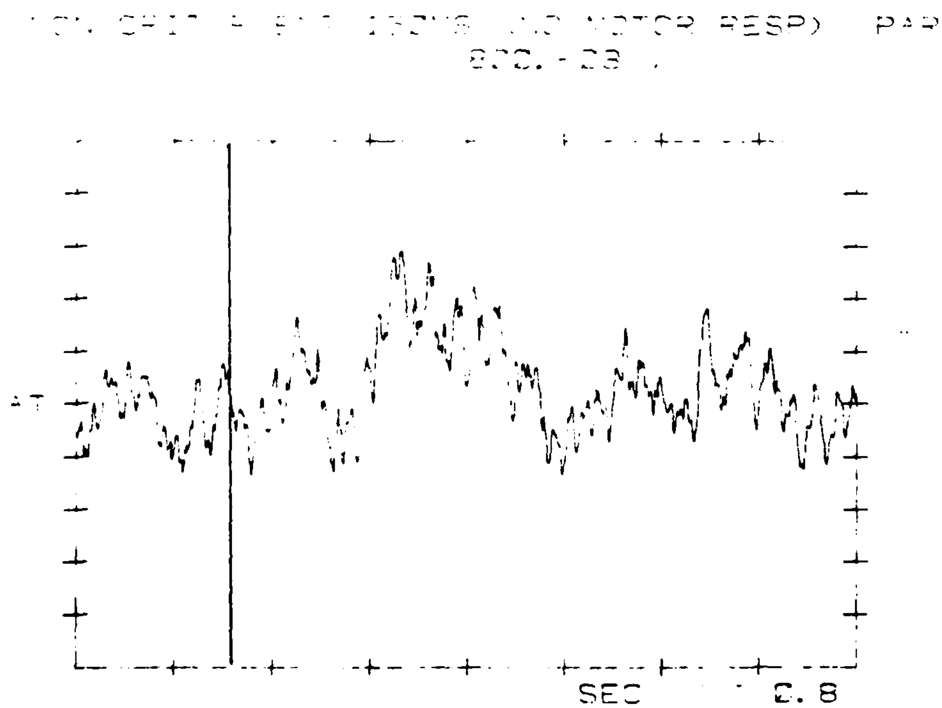
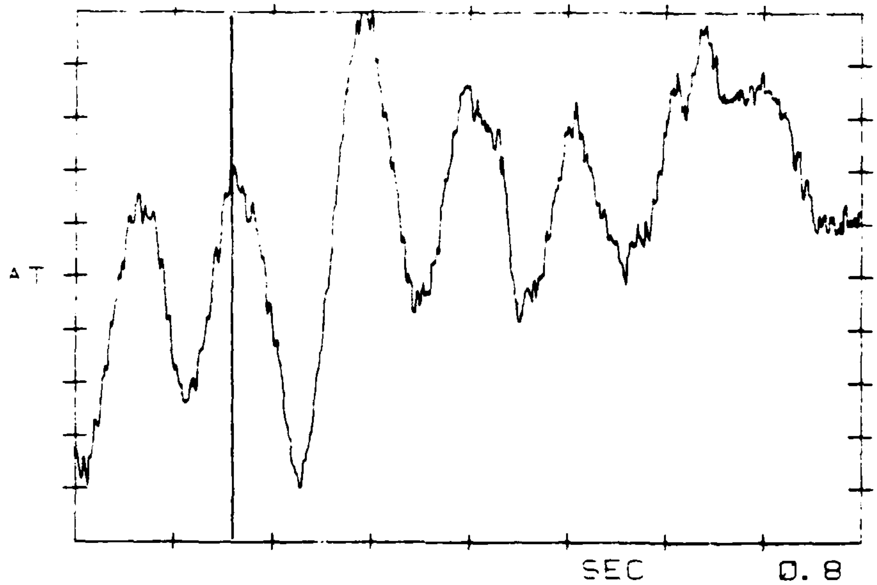


Fig 34. Condition 12/Subject 3

#4 CRIT EVENT 150MS (NO MOTOR RESP) PAR
600.-03 V



#4 NON-CRIT EVENT 150MS (NO MOTOR RESP) PAR
600.-03 V

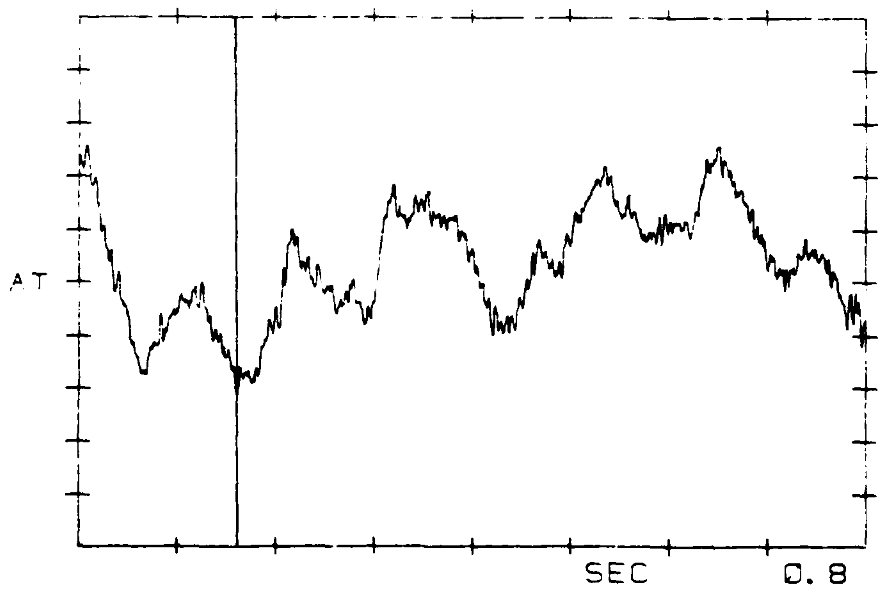
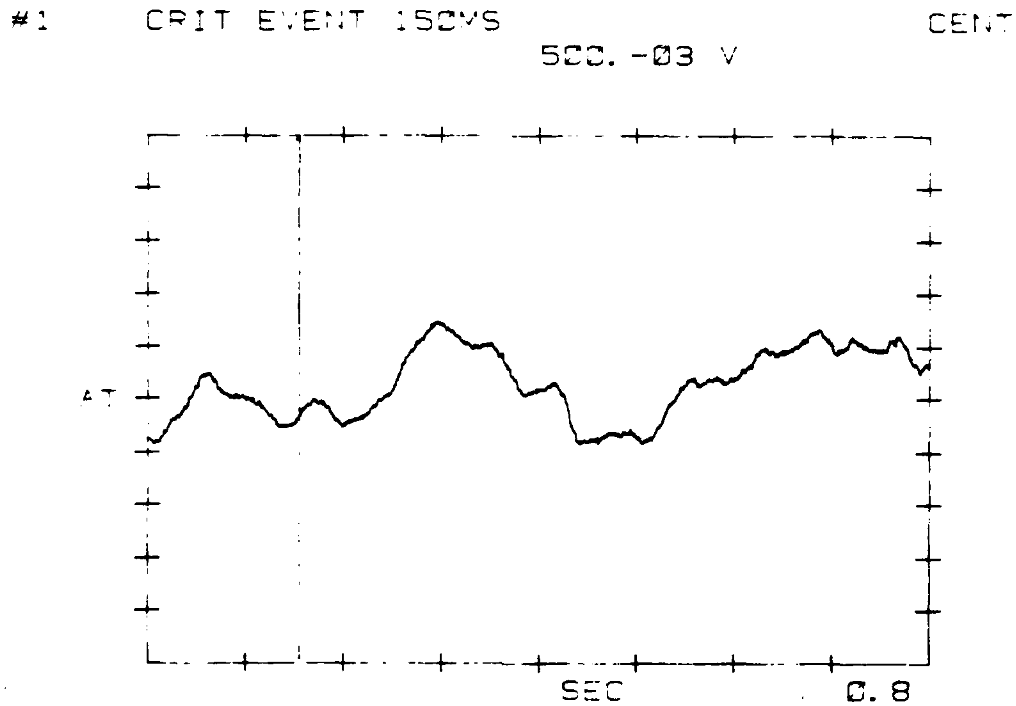


Fig 35. Condition 12/Subject 4



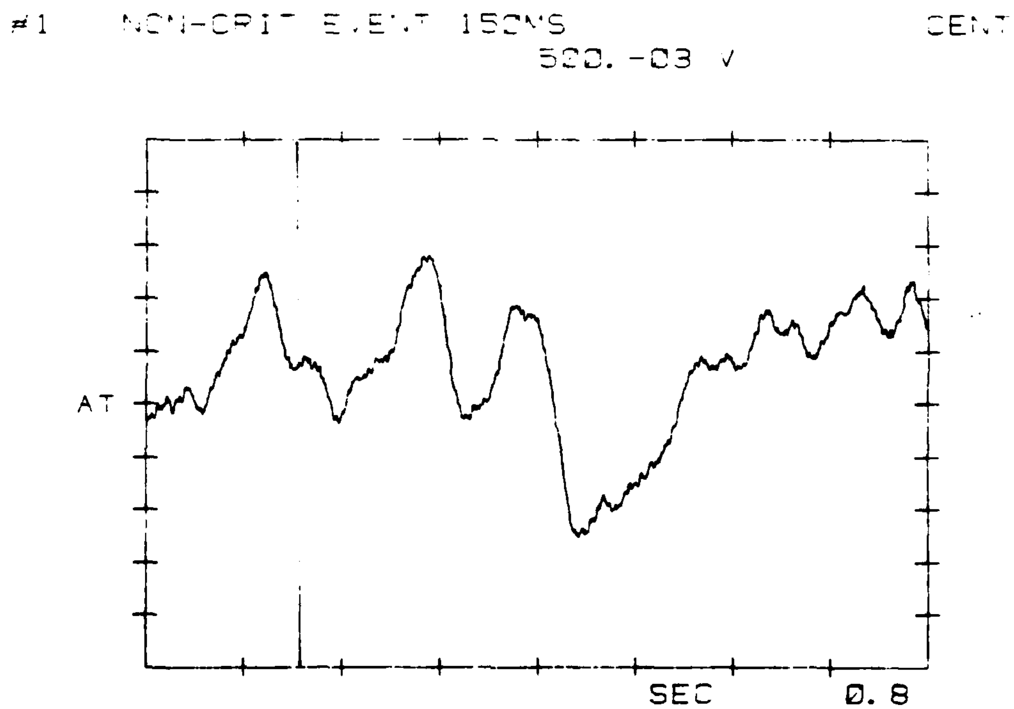
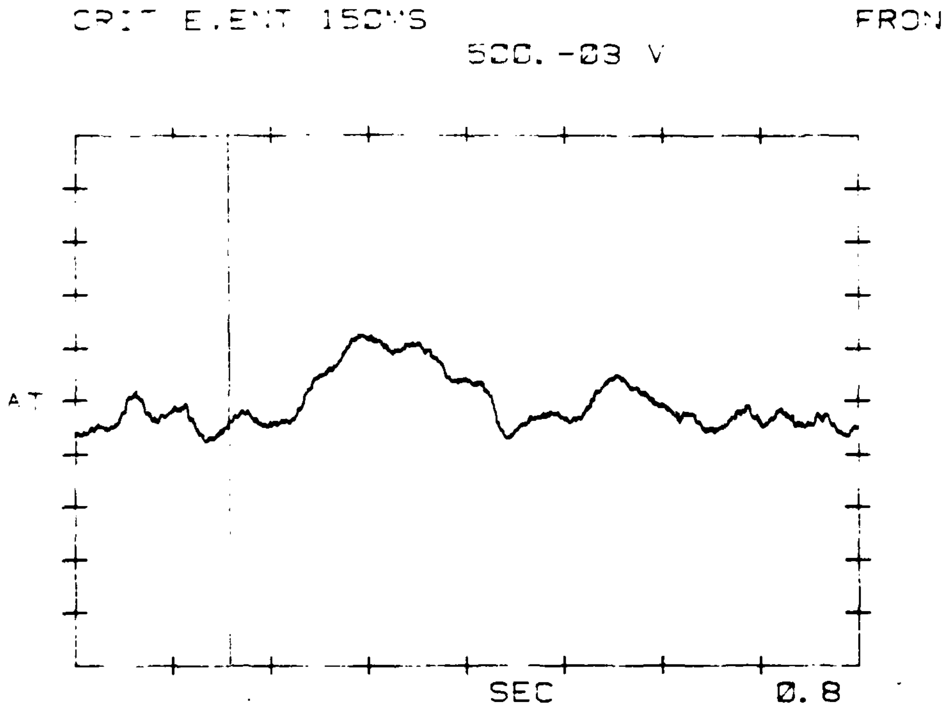


Fig 36. Condition 2/Subject 1/Cz Site



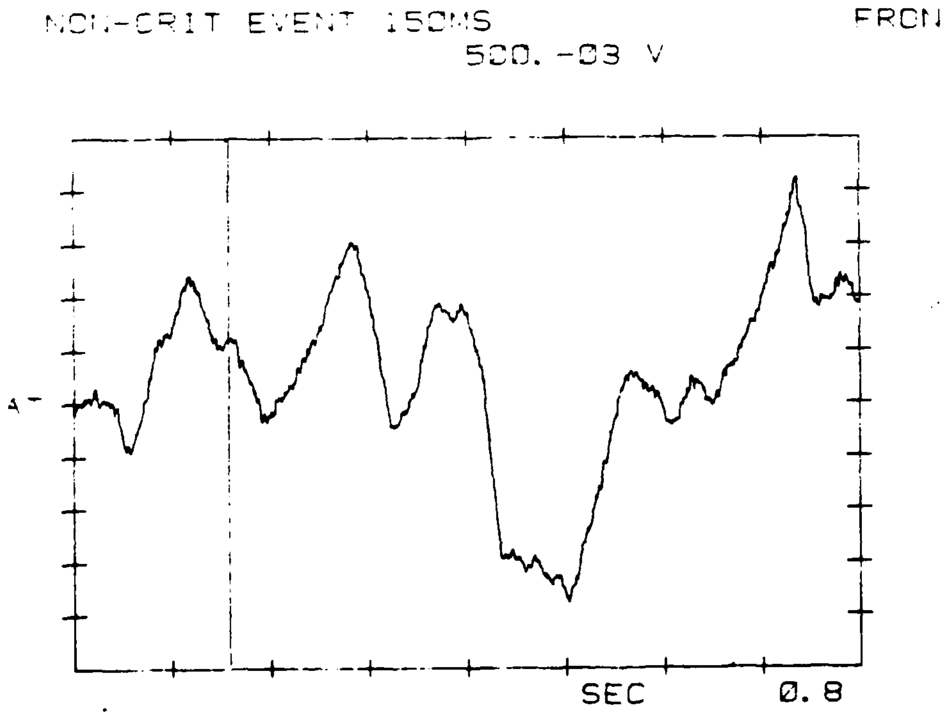
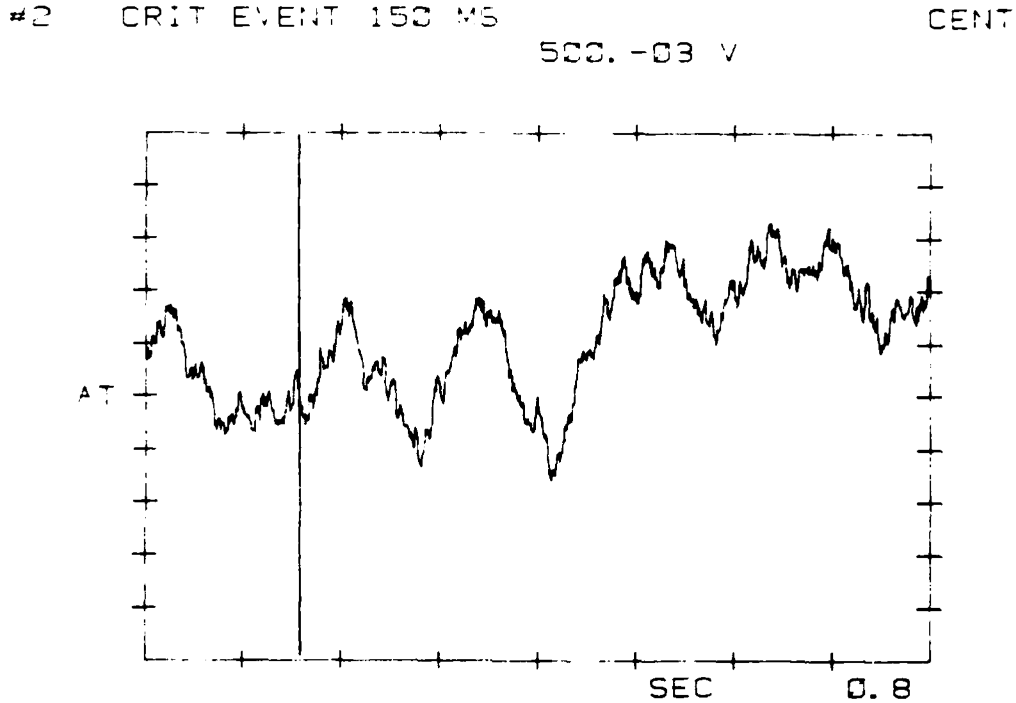


Fig 37. Condition 2/Subject 1/Fz Site



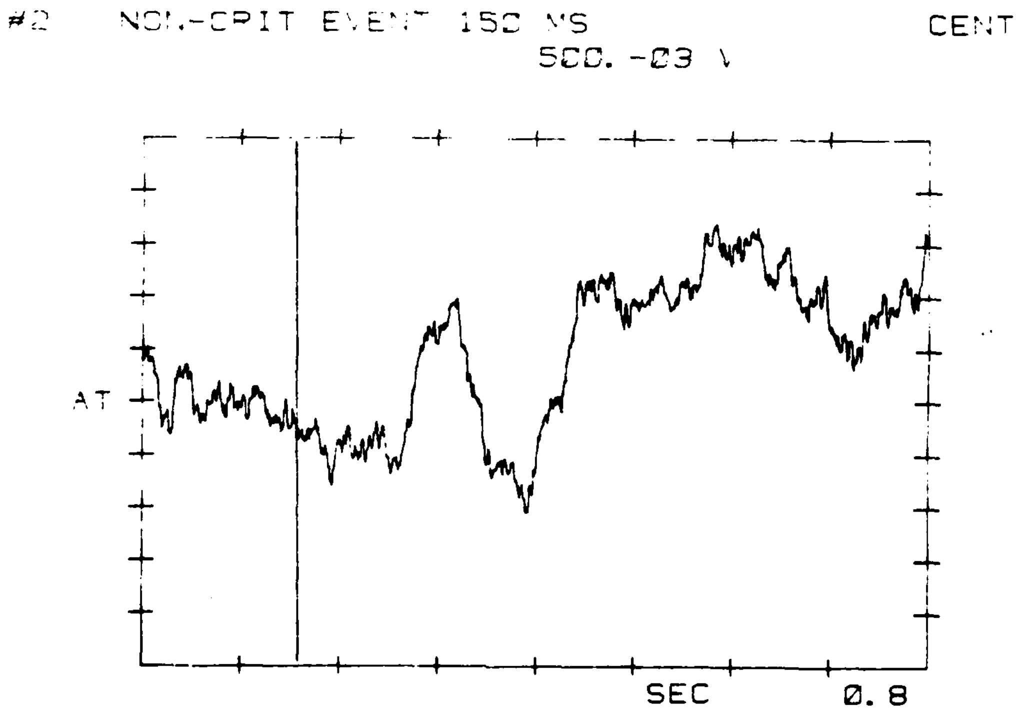
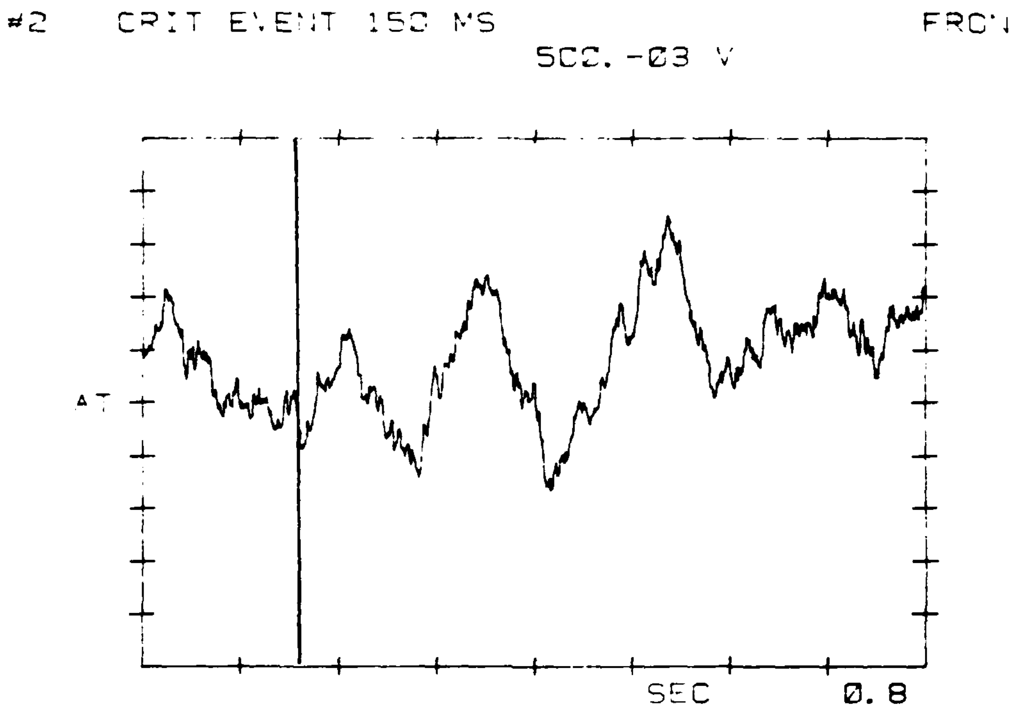


Fig 38. Condition 2/Subject 2/Cz Site



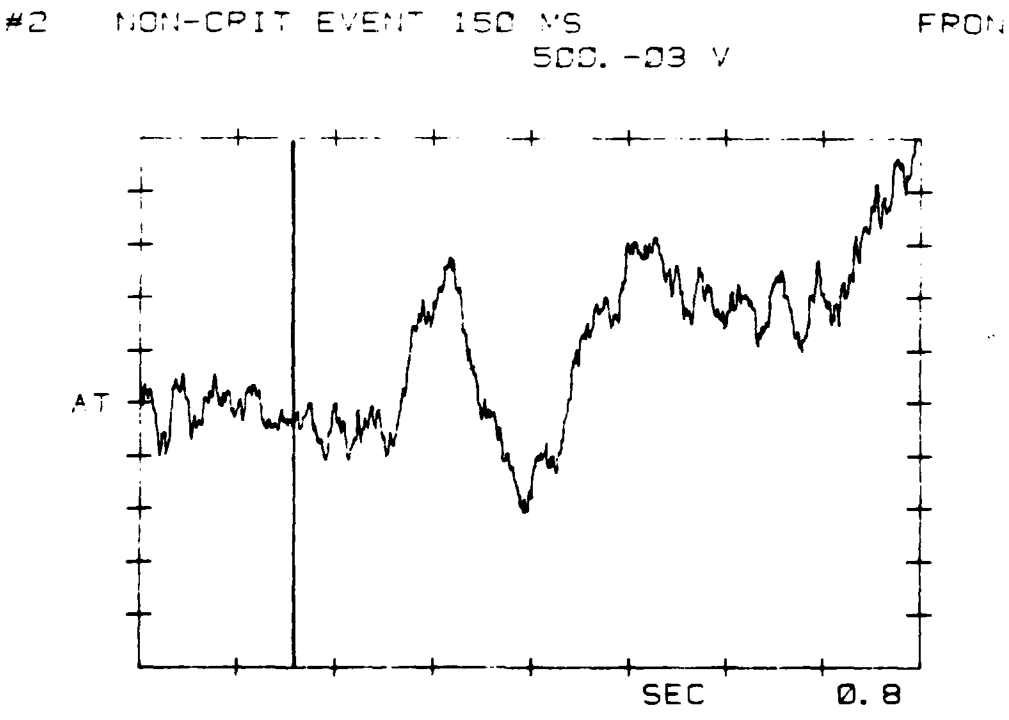
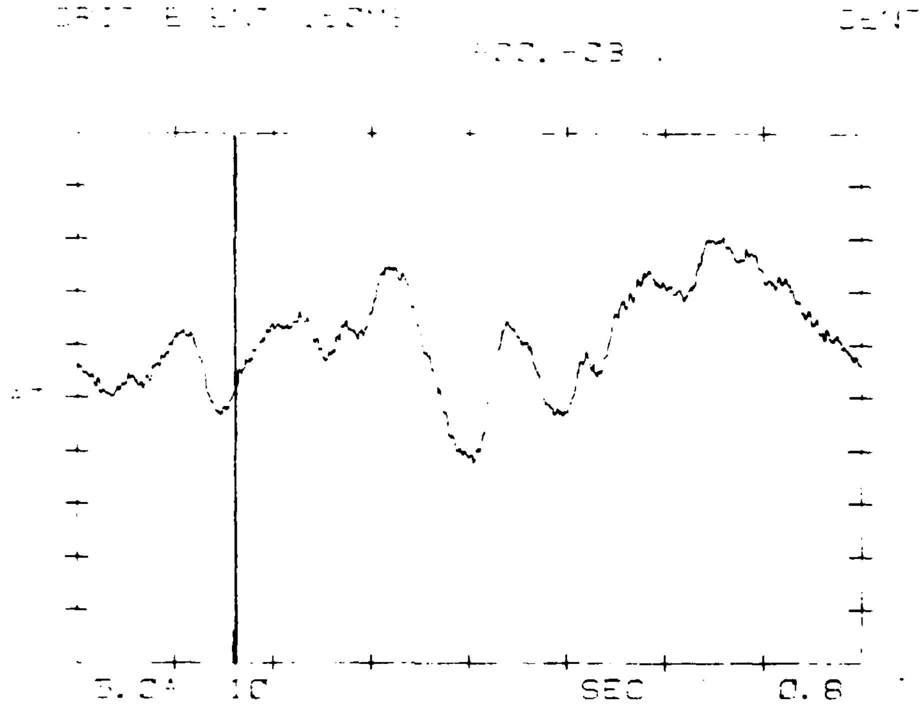


Fig 39. Condition 2/Subject 2/Fz Site



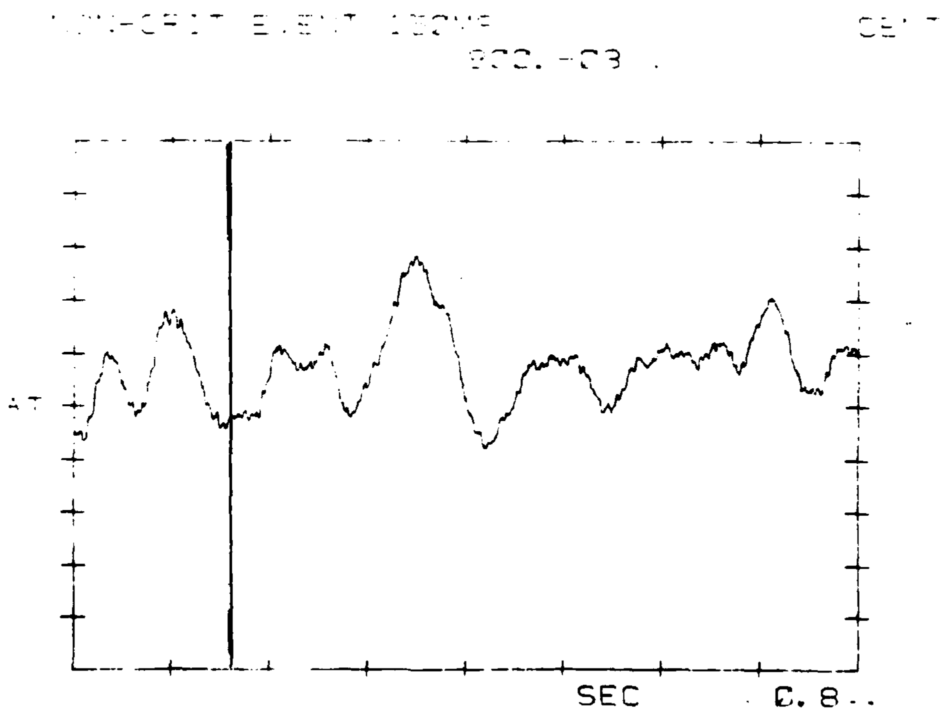
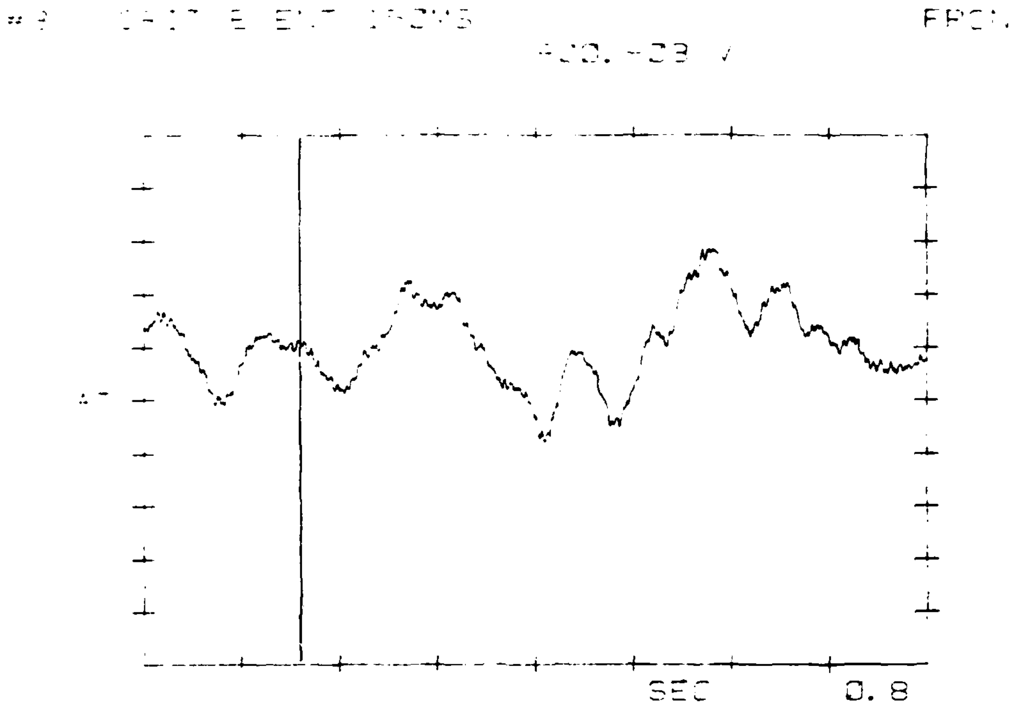


Fig 40. Condition 2/Subject 3/Cz Site



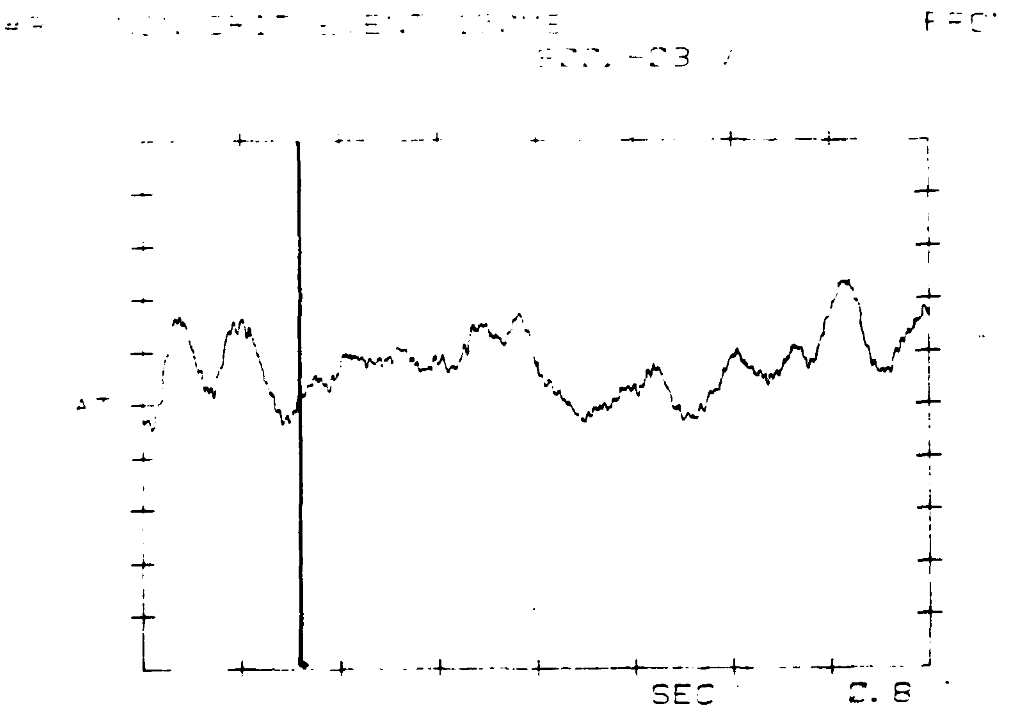
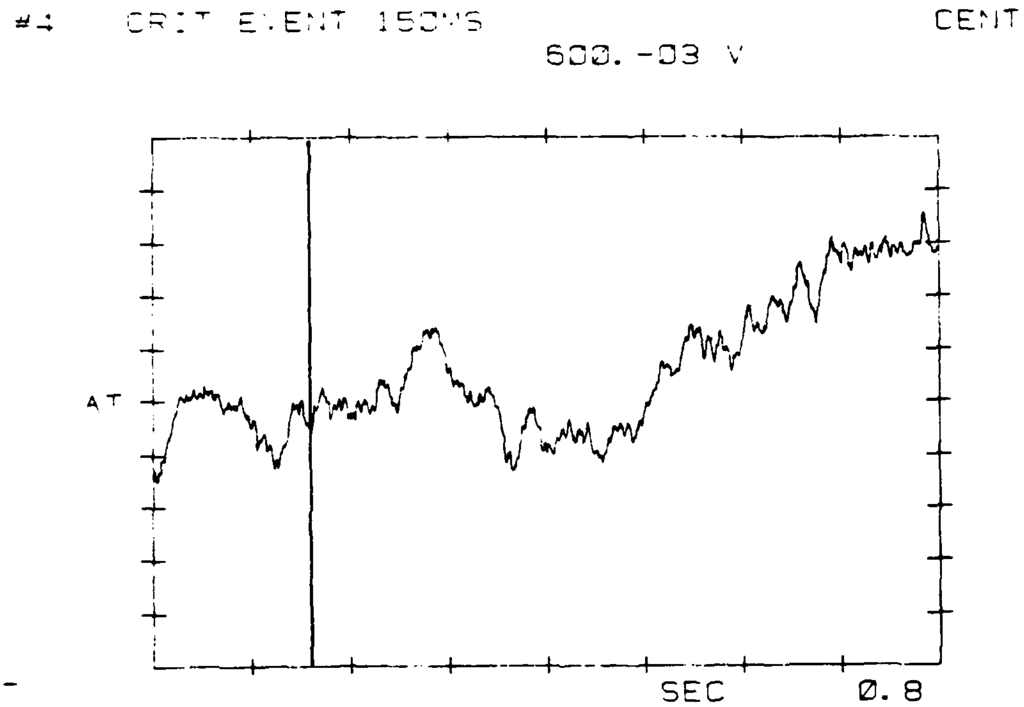


Fig 41. Condition 2/Subject 3/Fz Site



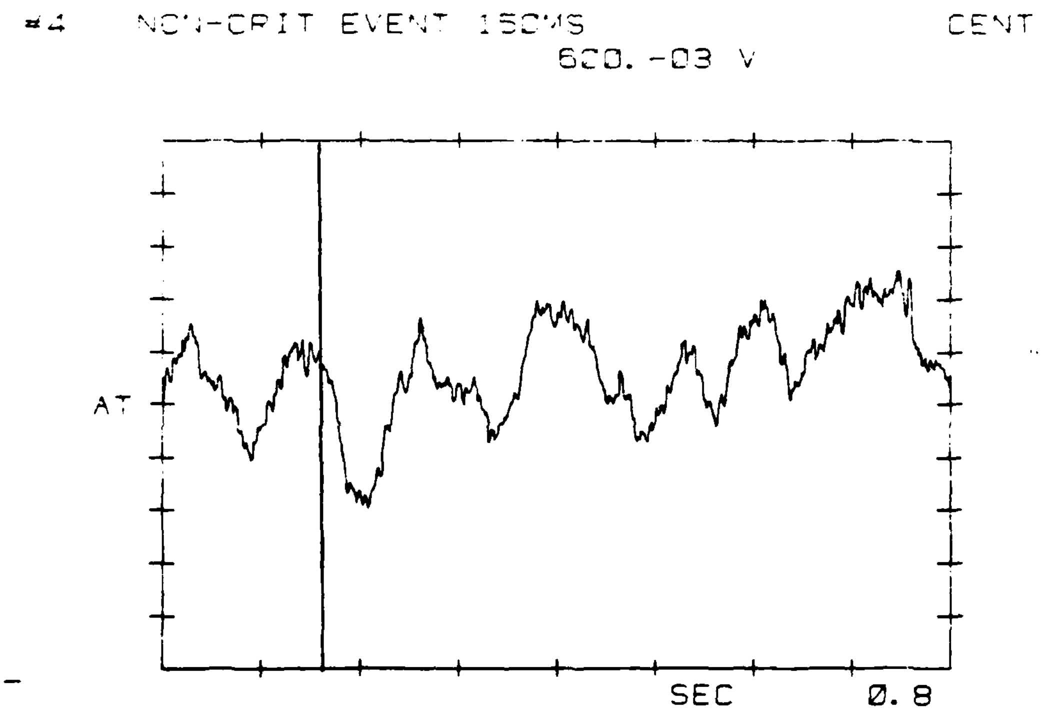
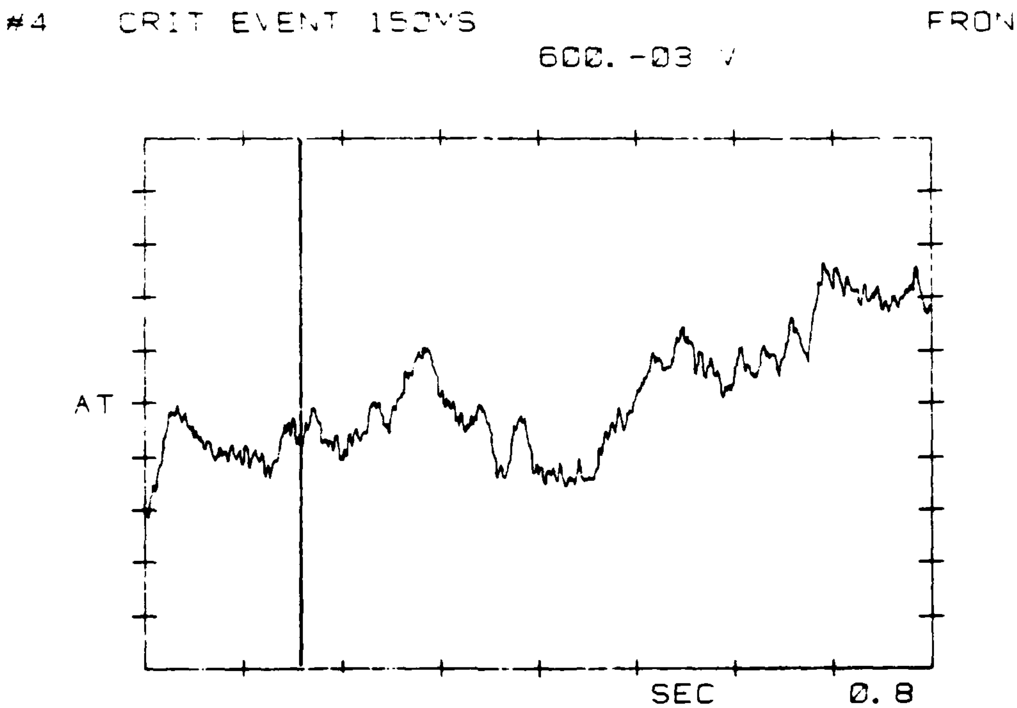


Fig 42. Condition 2/Subject 4/Cz Site



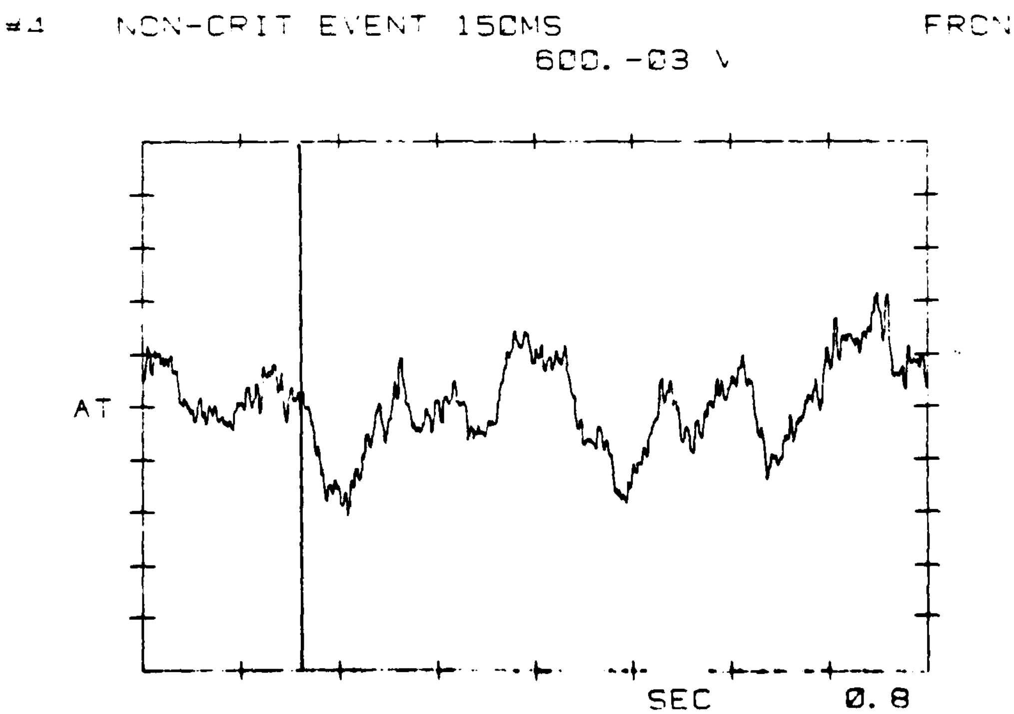


Fig 43. Condition 2/Subject 4/Fz Site

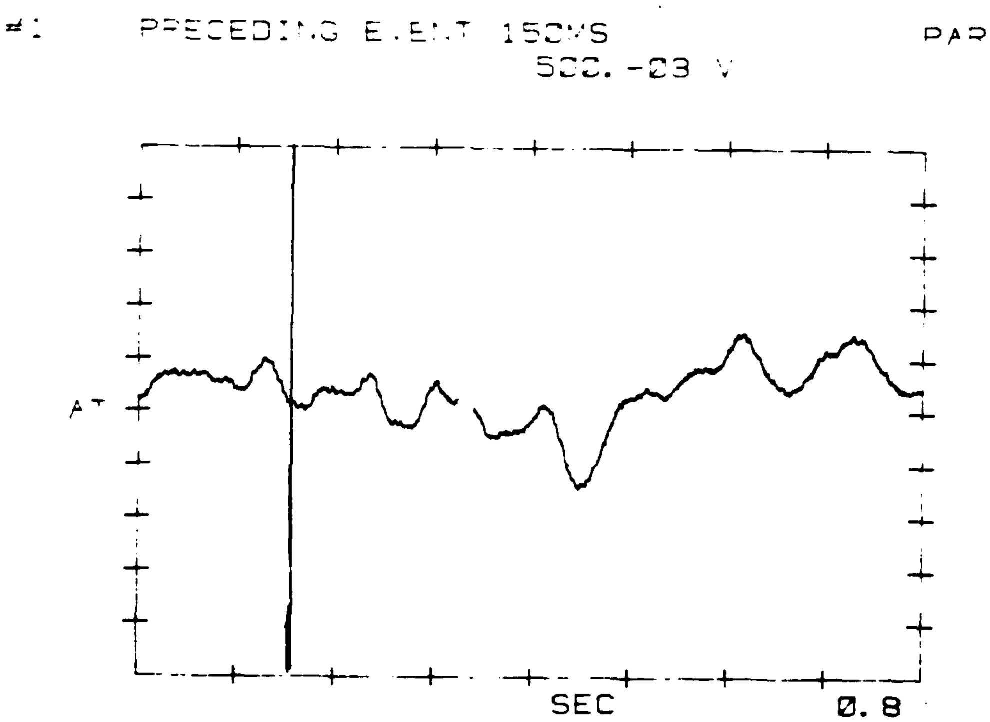


Fig 44. Condition 2/Subject 1/Preceding Event

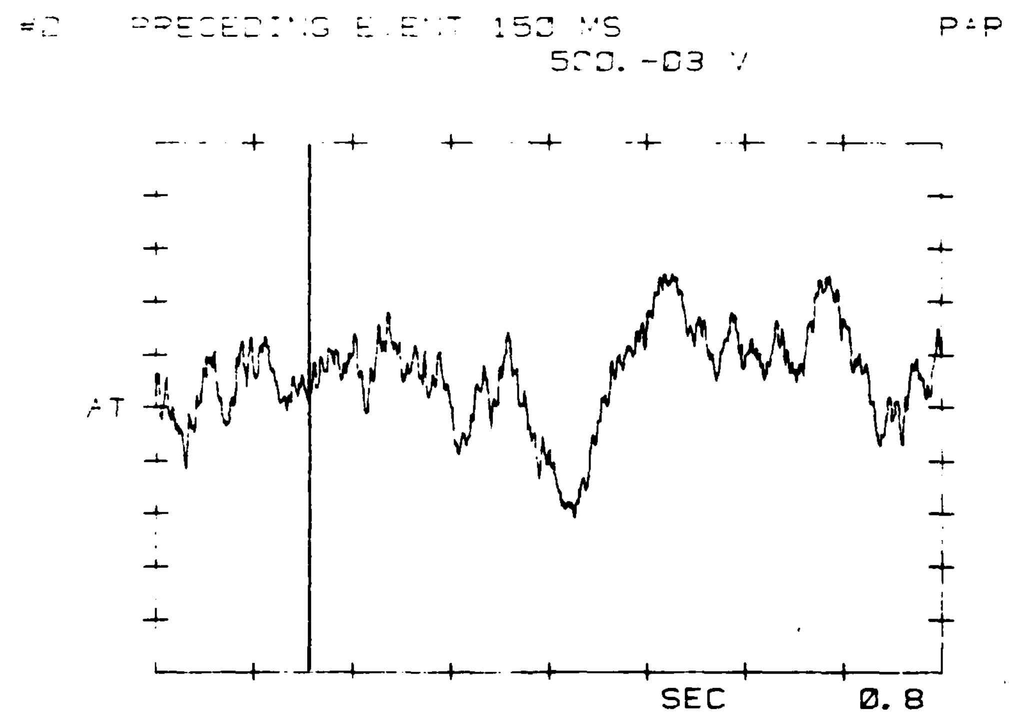


Fig 45. Condition 2/Subject 2/Preceding Event

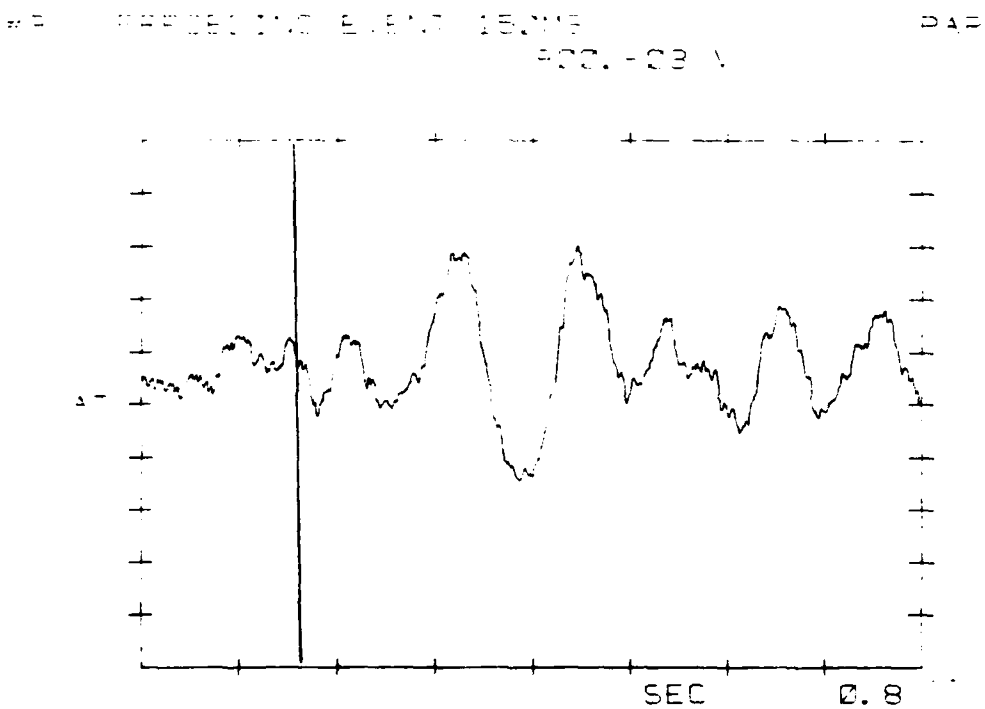


Fig 46. Condition 2/Subject 3/Preceding Event

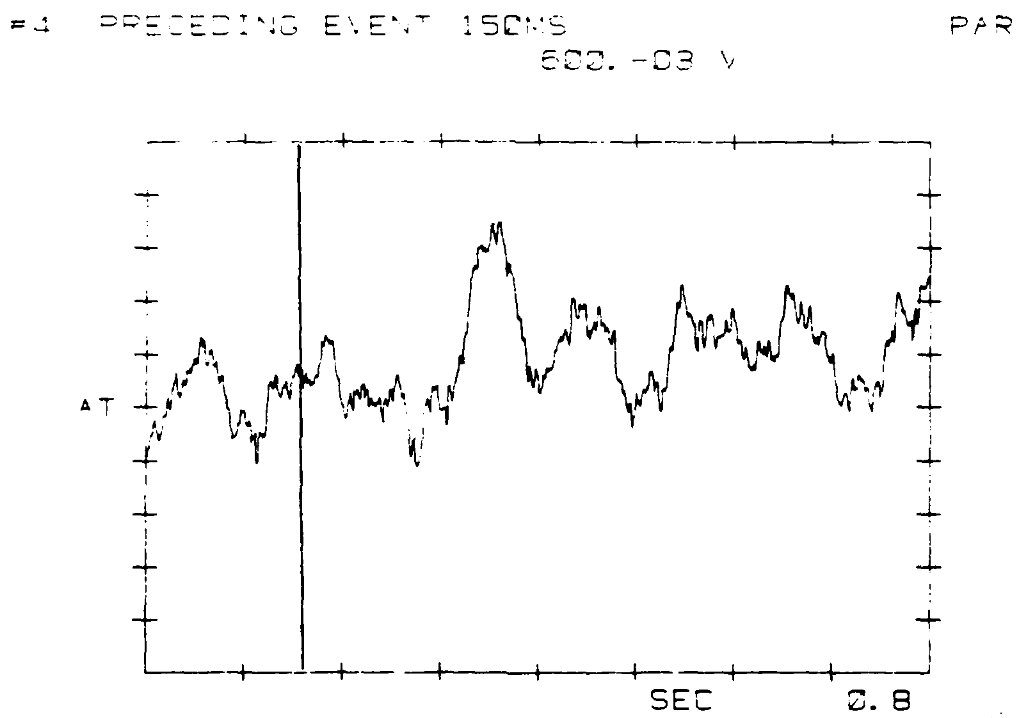
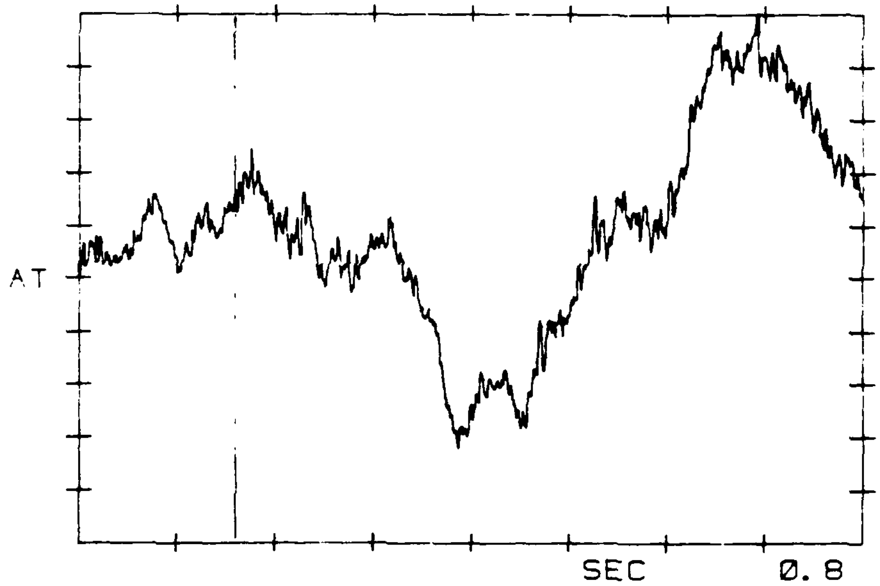


Fig 47. Condition 2/Subject 4/Preceding Event

#1 CRIT EVENT 150MS (EASY TRACKING) PAR
500.-03 V



#1 NON-CRIT EVENT 150MS (EASY TRACKING) PAR
500.-03 V

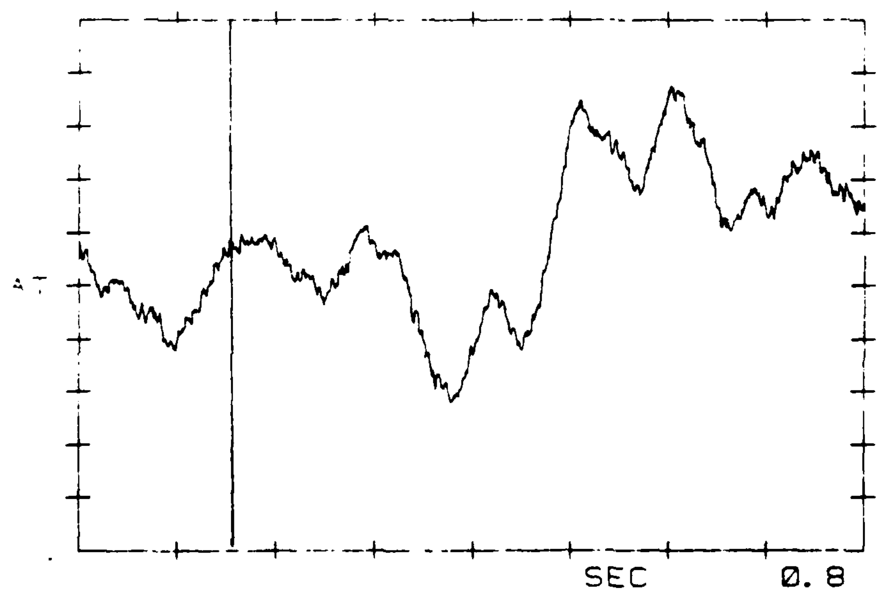
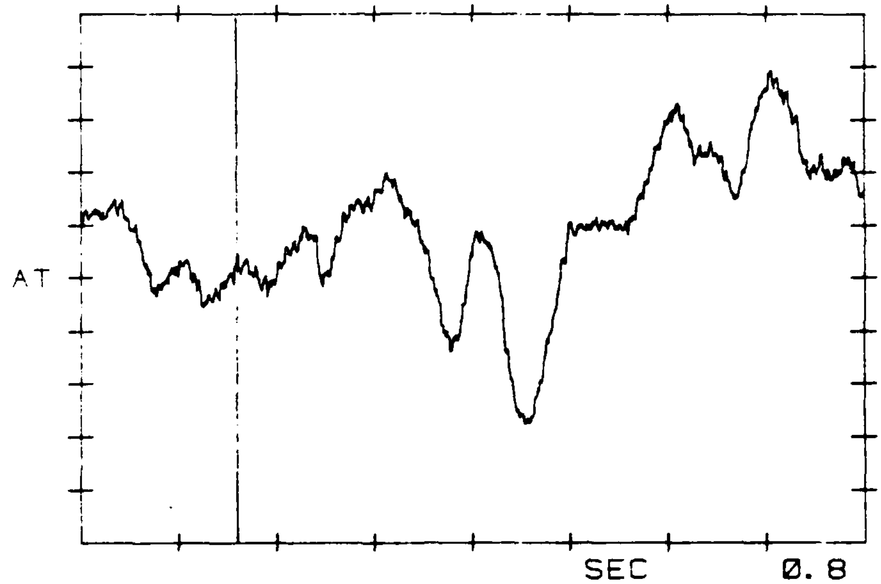


Fig 48. Condition 6/Subject 1

#1 CRIT EVENT 150MS (HARD TRACKING) PAR
500. -03 V



#1 NON-CRIT EVENT 150MS (HARD TRACKING) PAR
500. -03 V

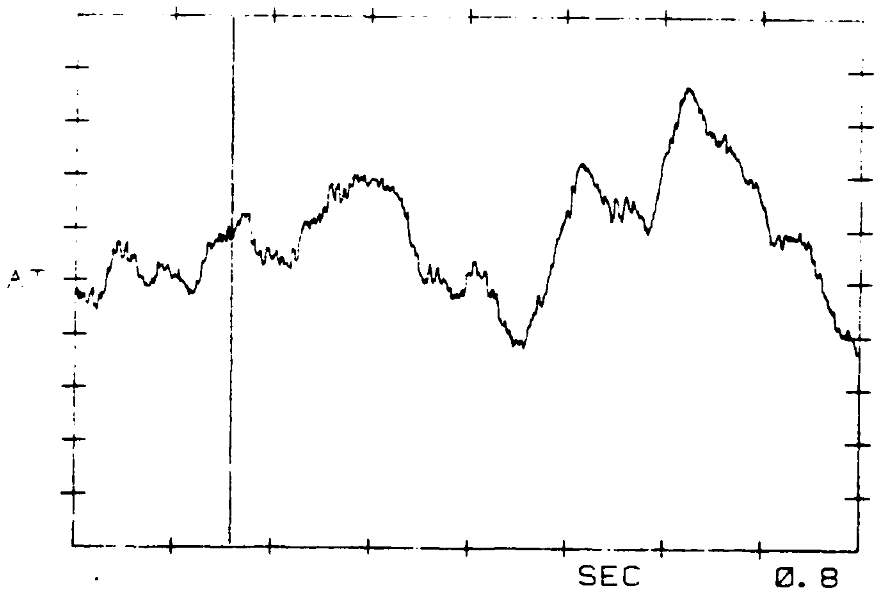
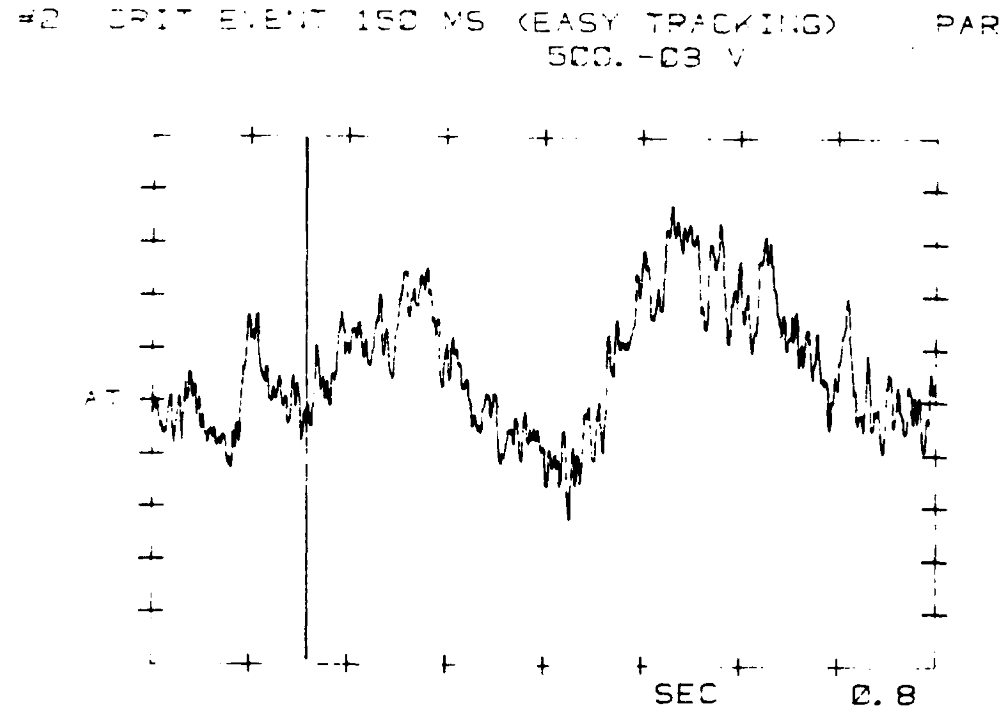


Fig 49. Condition 7/Subject 1



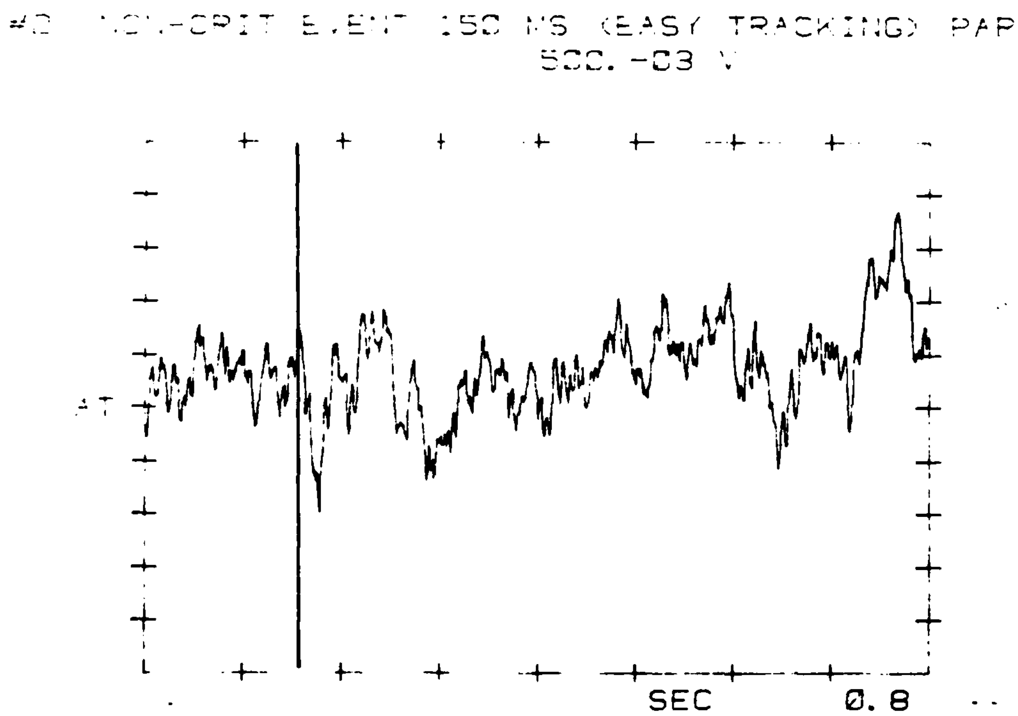
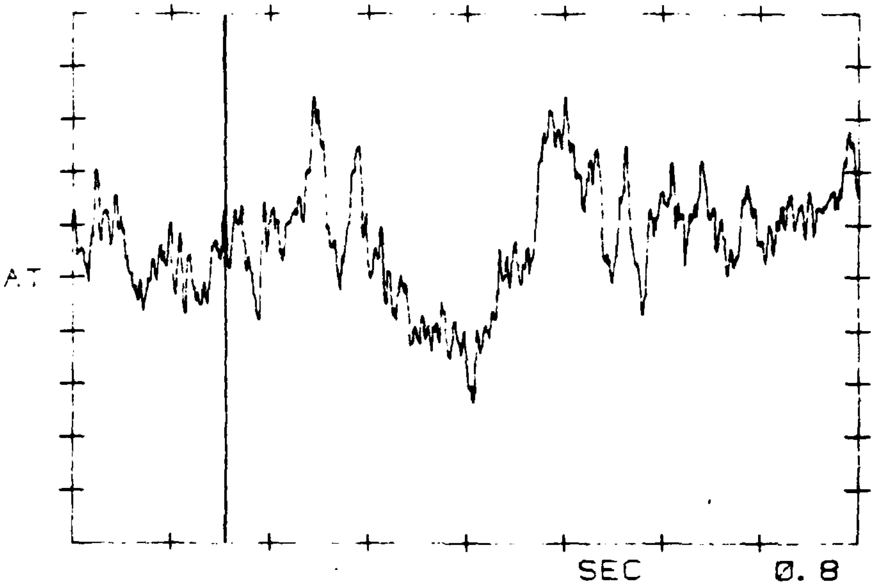


Fig 50. Condition 6/Subject 2

#2 CRIT EVENT 150 MS (HARD TRACKING) PAR
500.-03 V



#2 NON-CRIT EVENT 150 MS (HARD TRACKING) PAR
500.-03 V

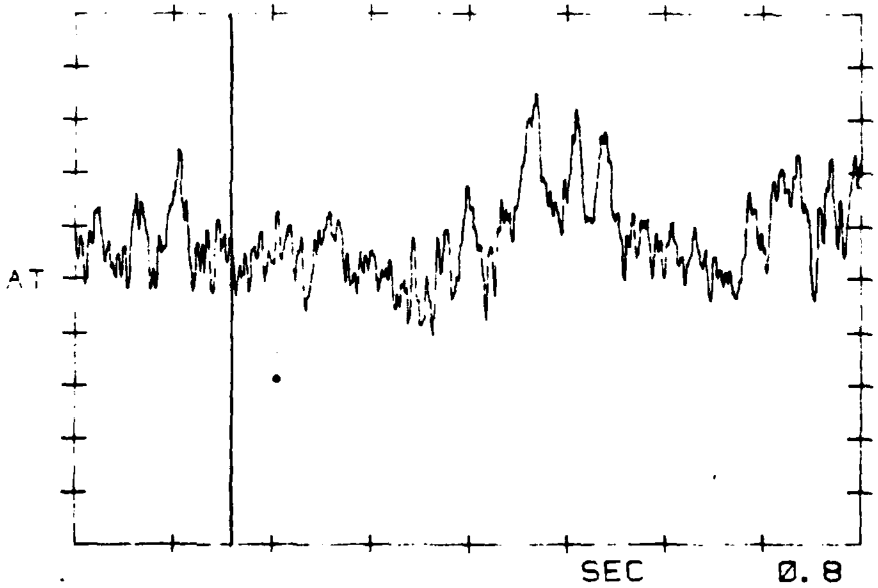
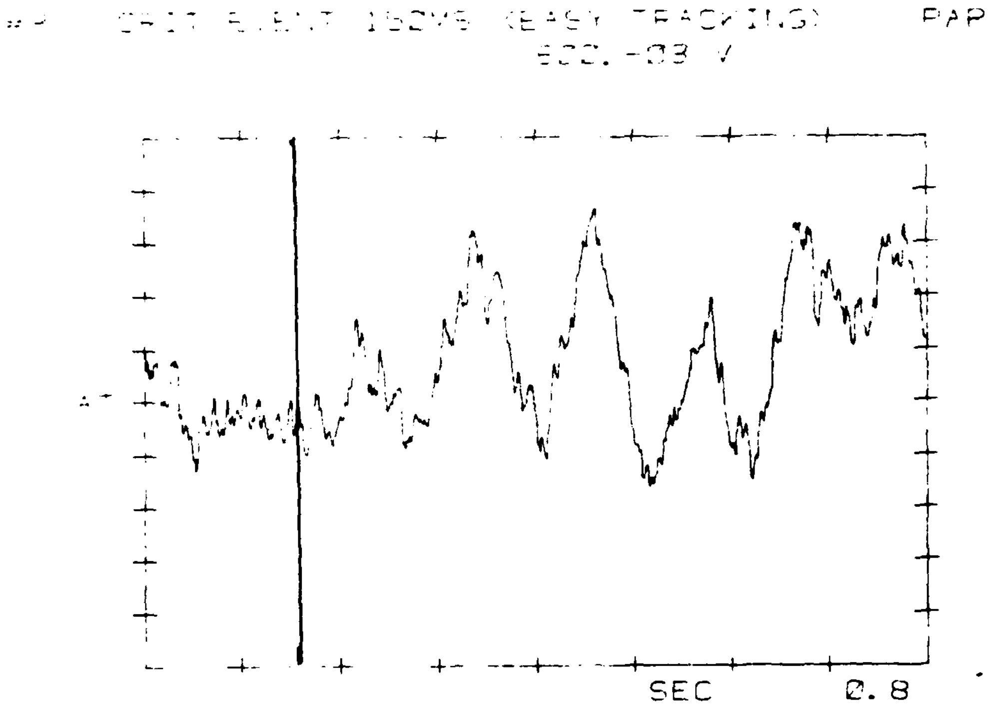


Fig 51. Condition 7/Subject 2



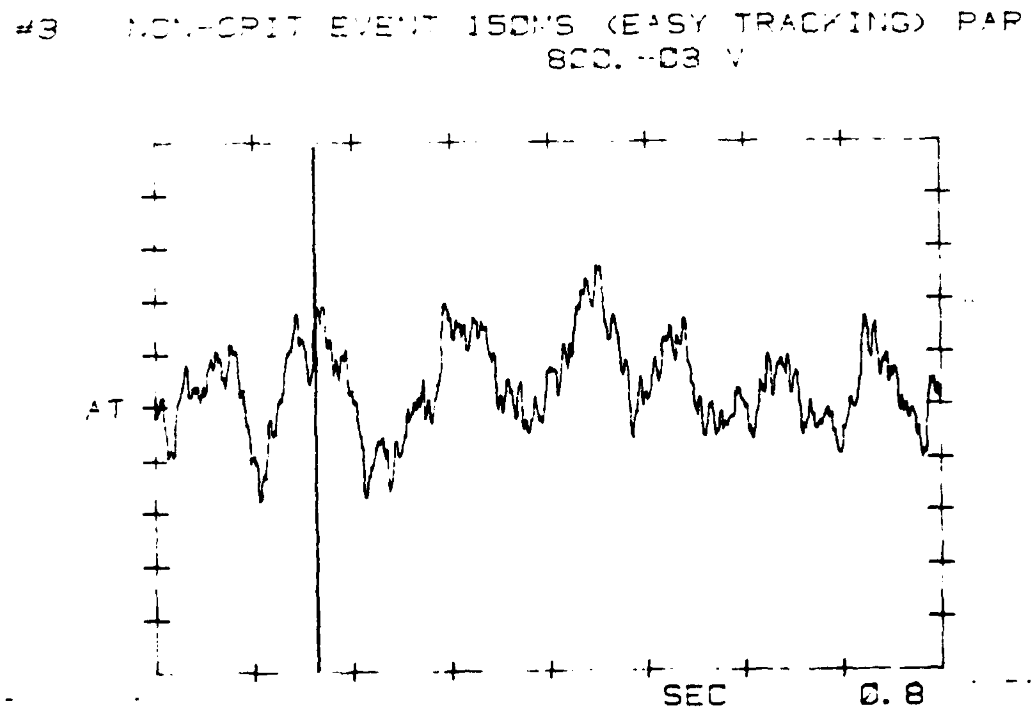
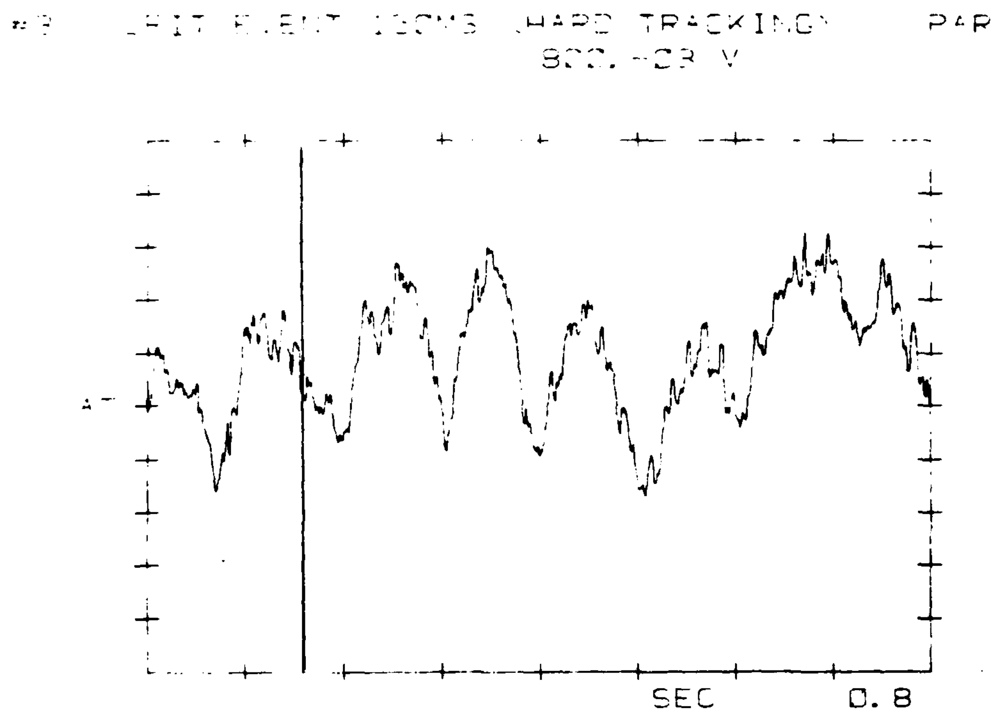


Fig 52. Condition 6/Subject 3



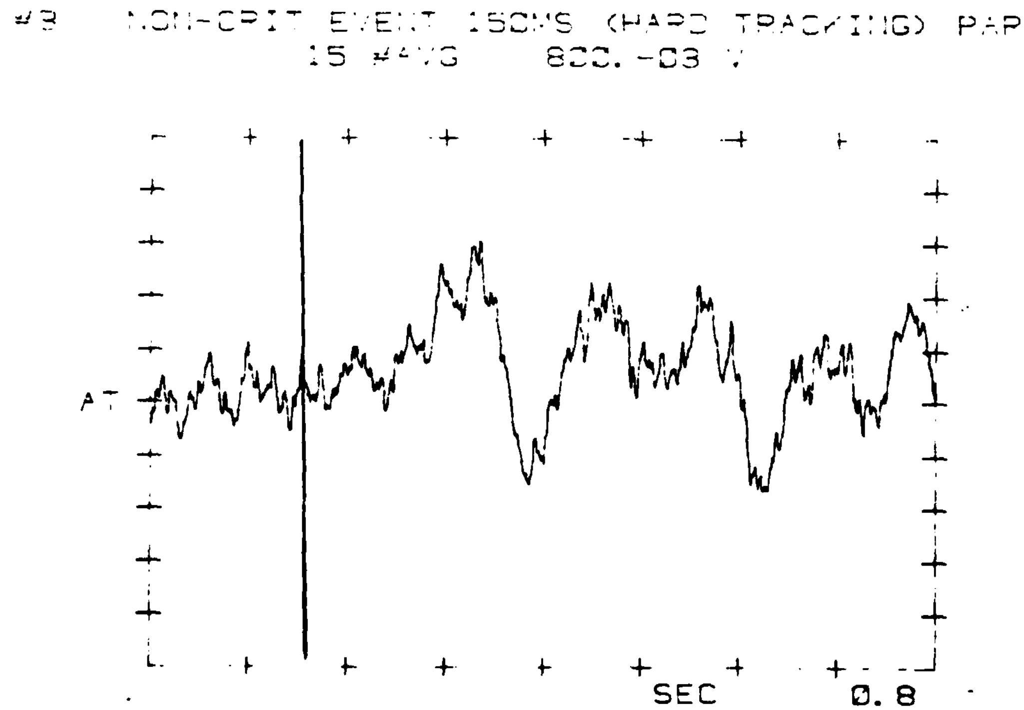
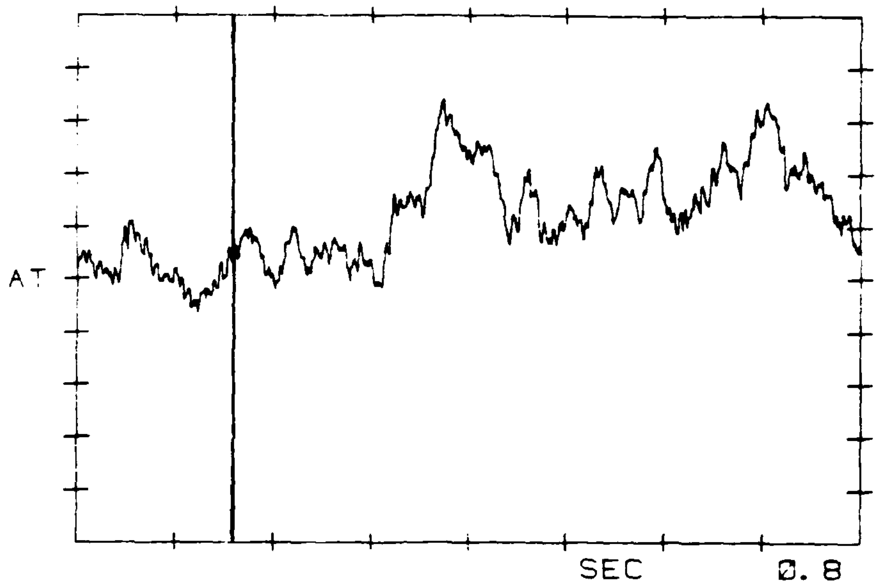


Fig 53. Condition 7/Subject 3

#4 CRIT EVENT 15CMS (EASY TRACKING) PAR
600. -03 V



#4 NON-CRIT EVENT 15CMS (EASY TRACKING) PAR
600. -03 V

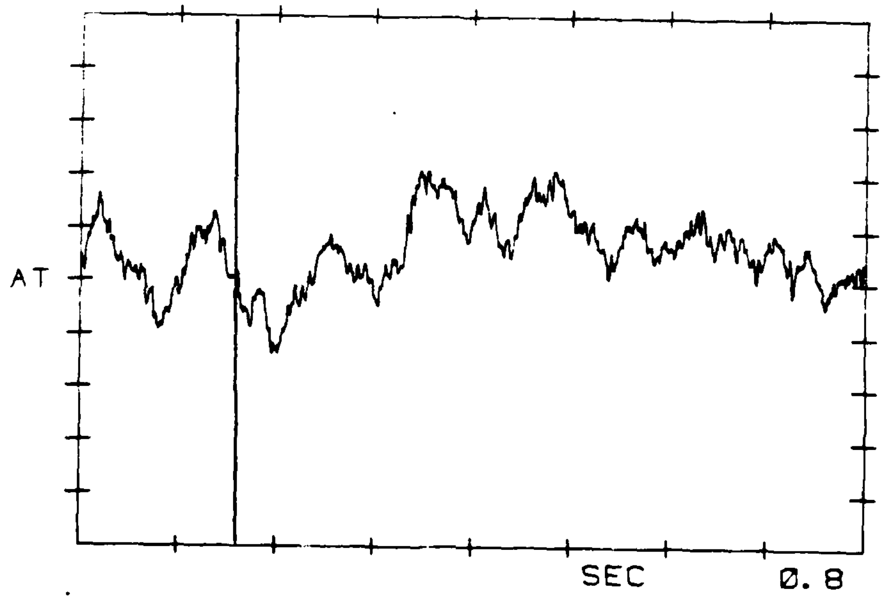
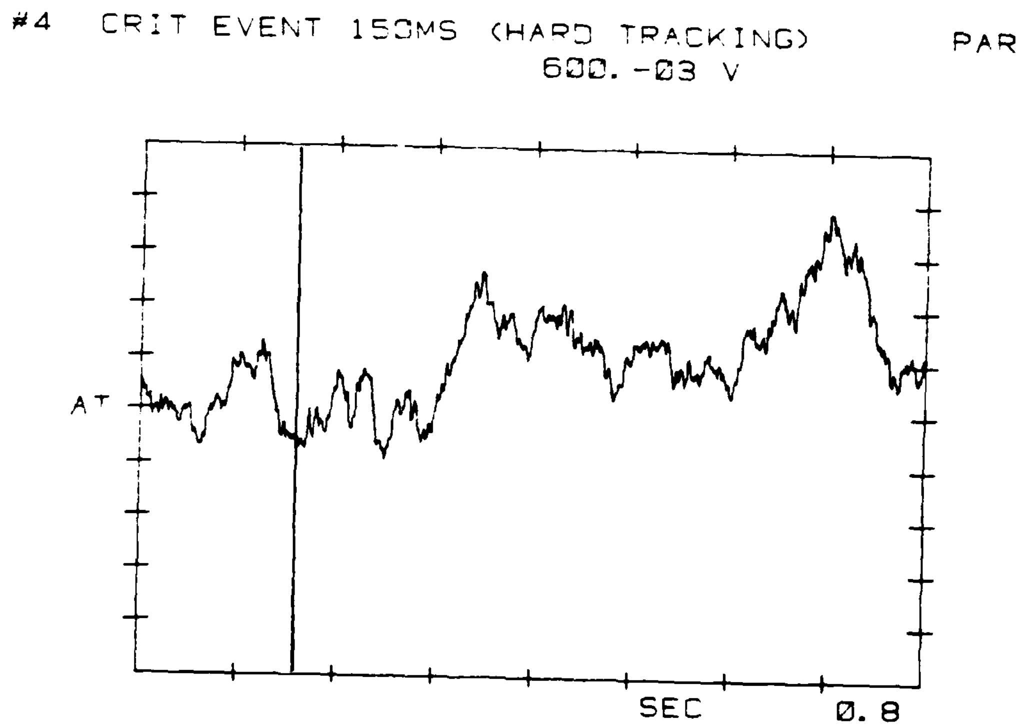


Fig 54. Condition 6/Subject 4



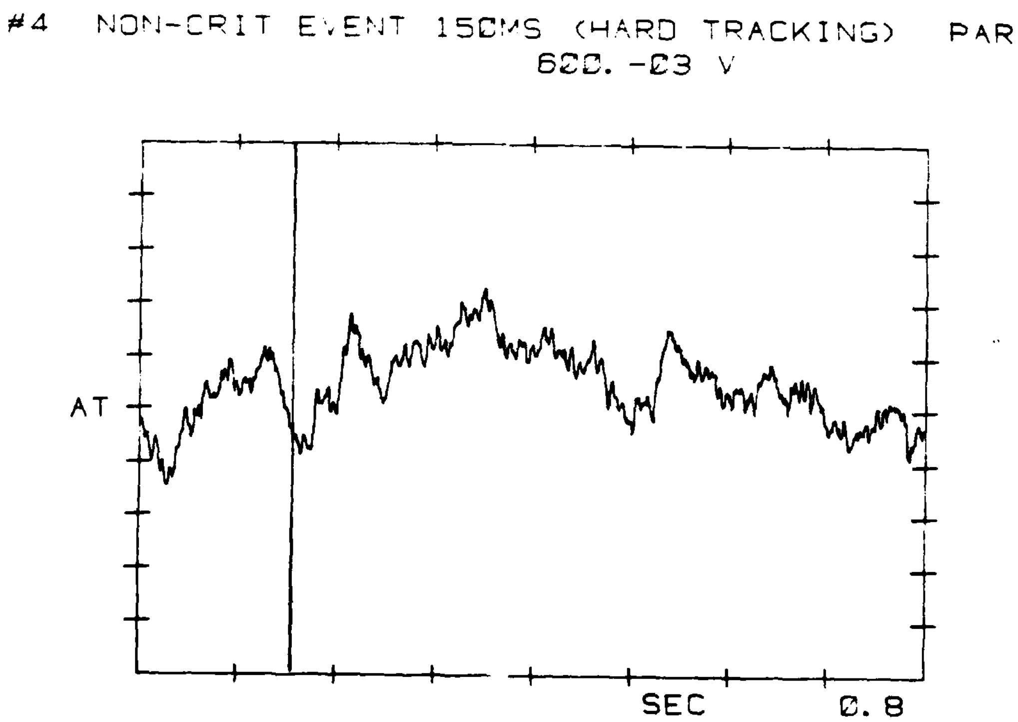
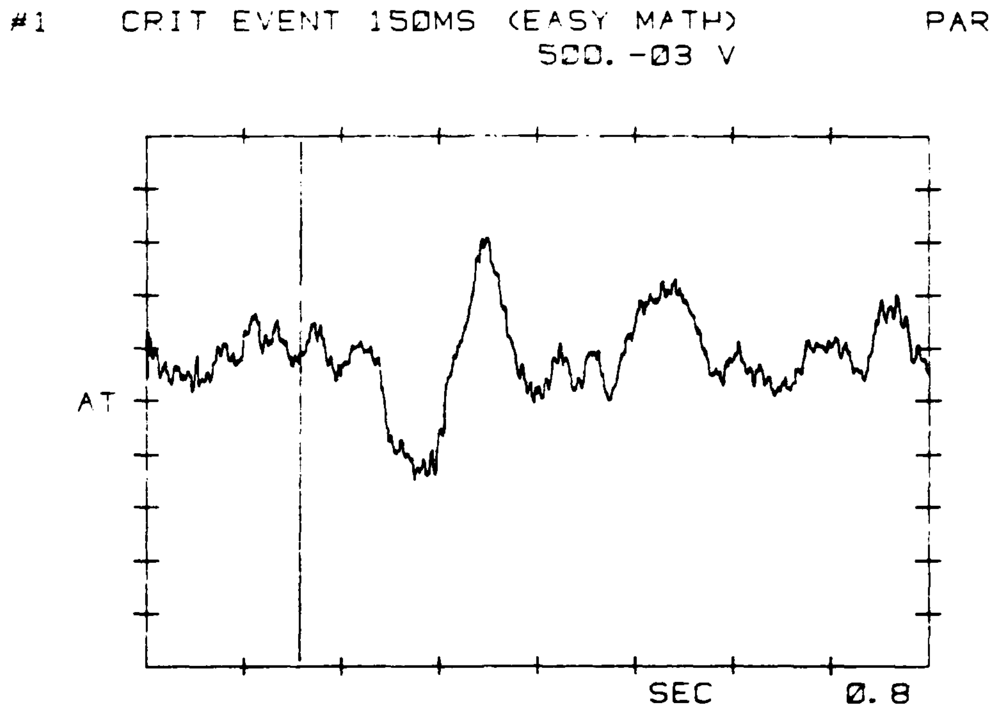


Fig 55. Condition 7/Subject 4



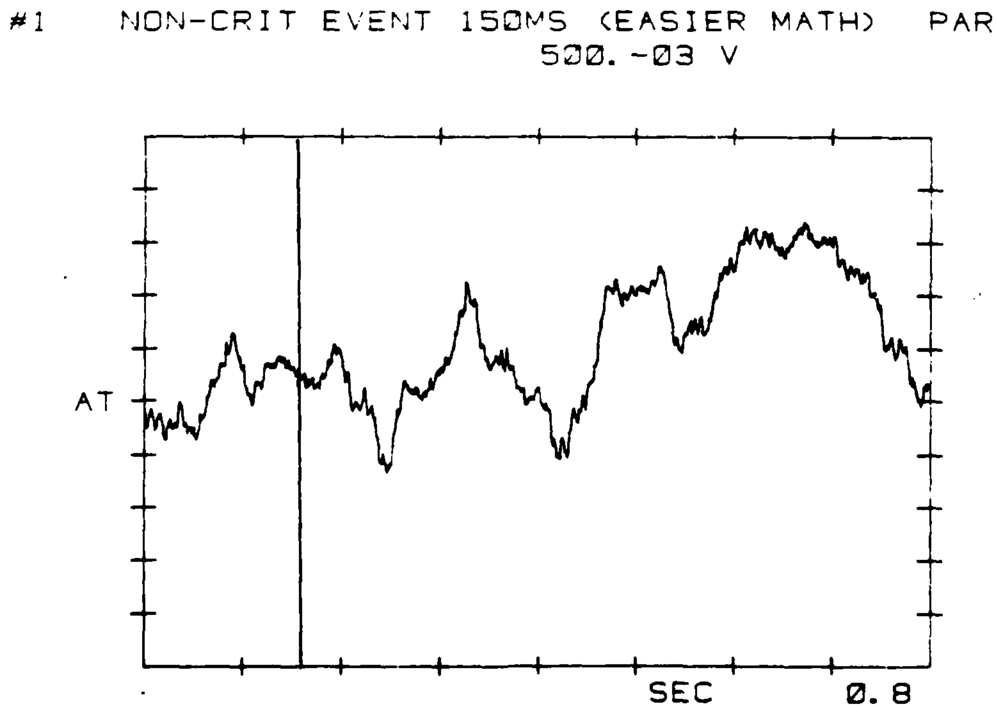
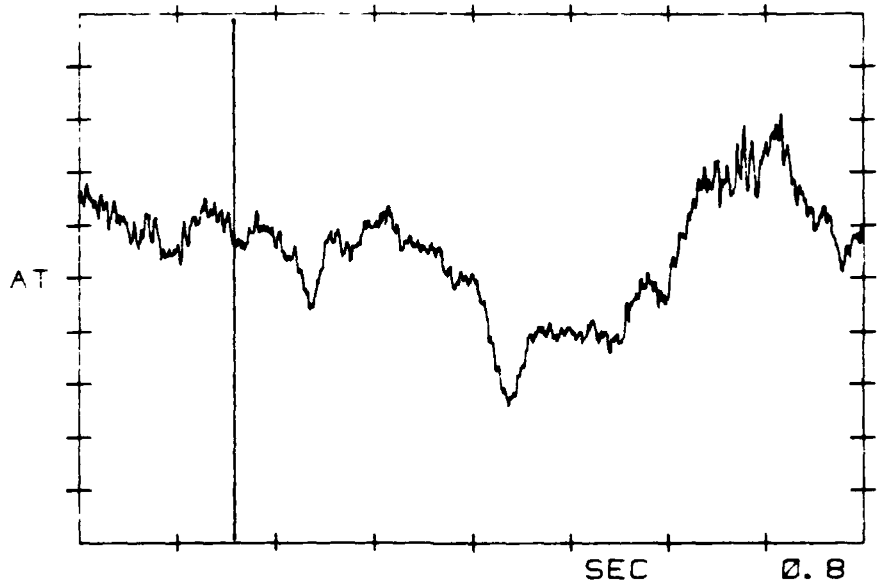


Fig 56. Condition 8/Subject 1

#1 CRIT EVENT 150MS (HARD MATH) PAR
500. -03 V



#1 NON-CRIT EVENT 150MS (HARD MATH) PAR
500. -03 V

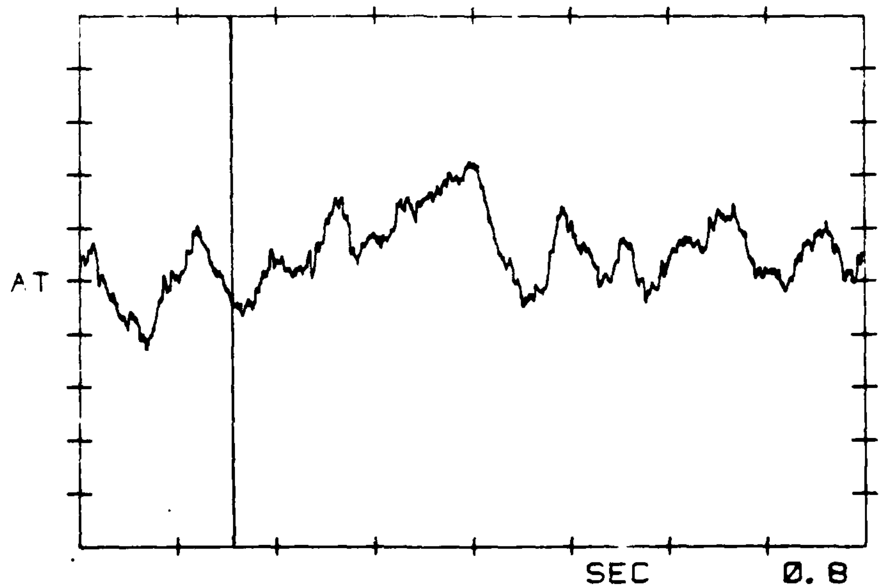
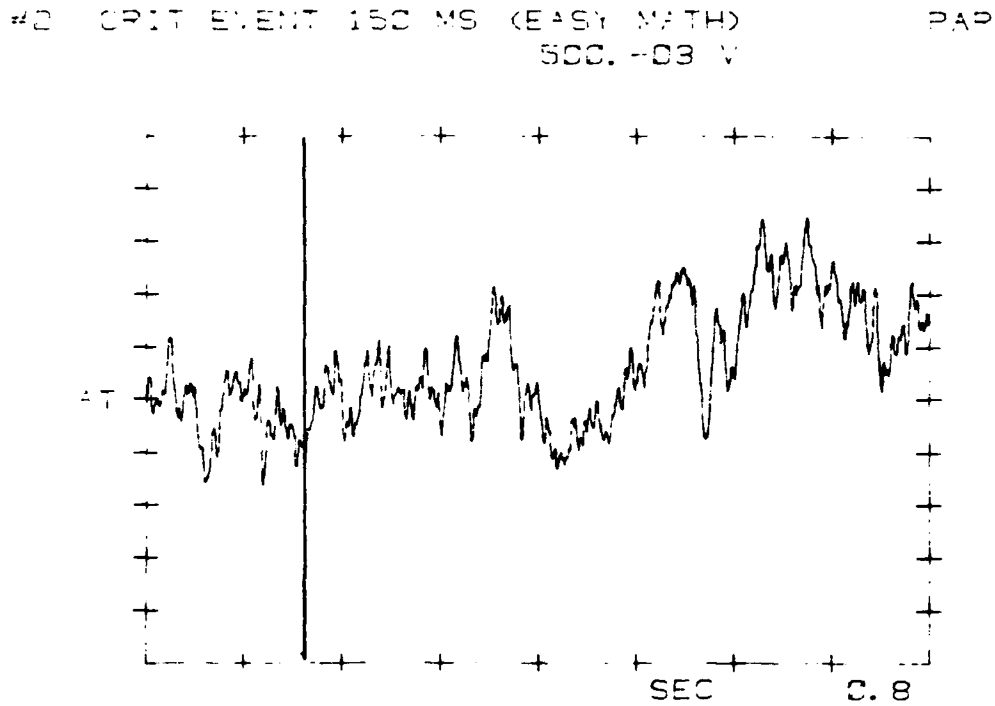


Fig 57. Condition 9/Subject 1



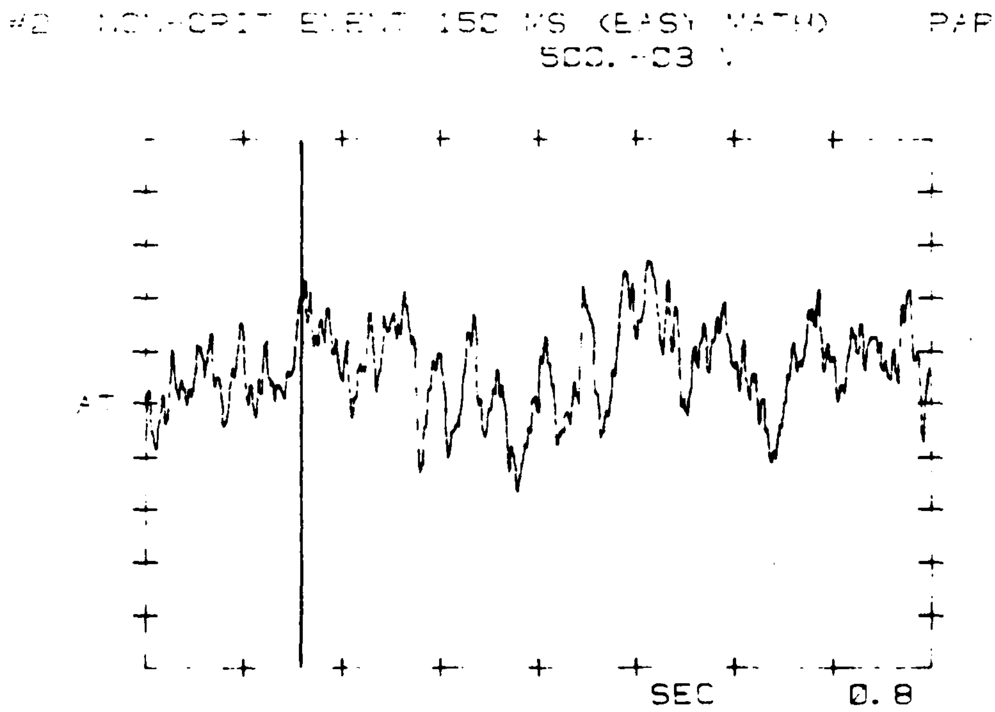
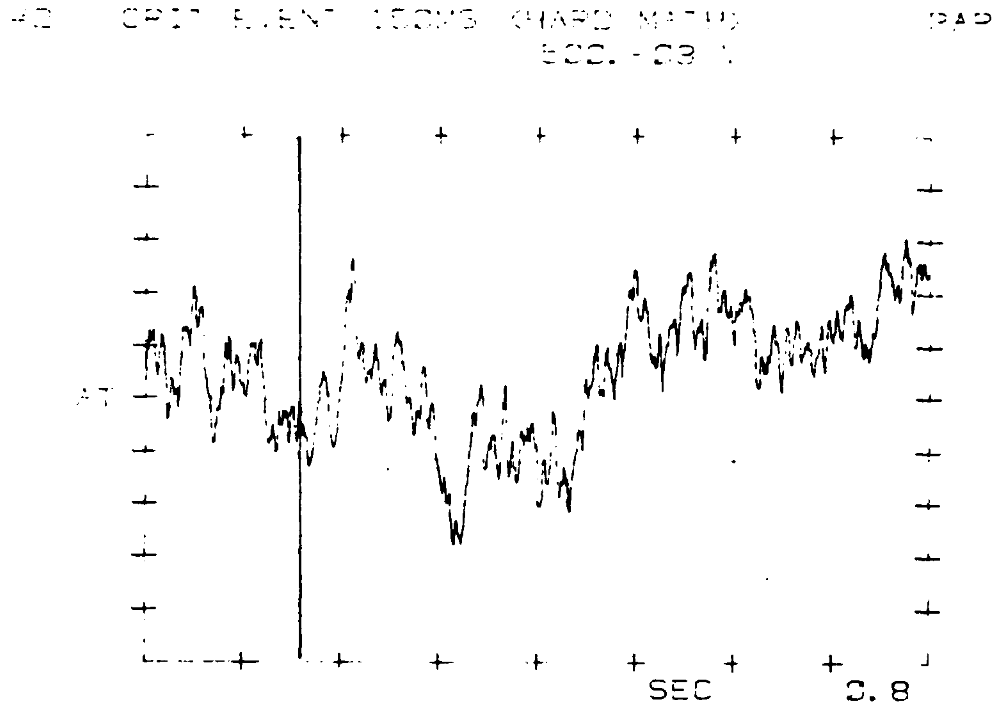


Fig 58. Condition 8/Subject 2



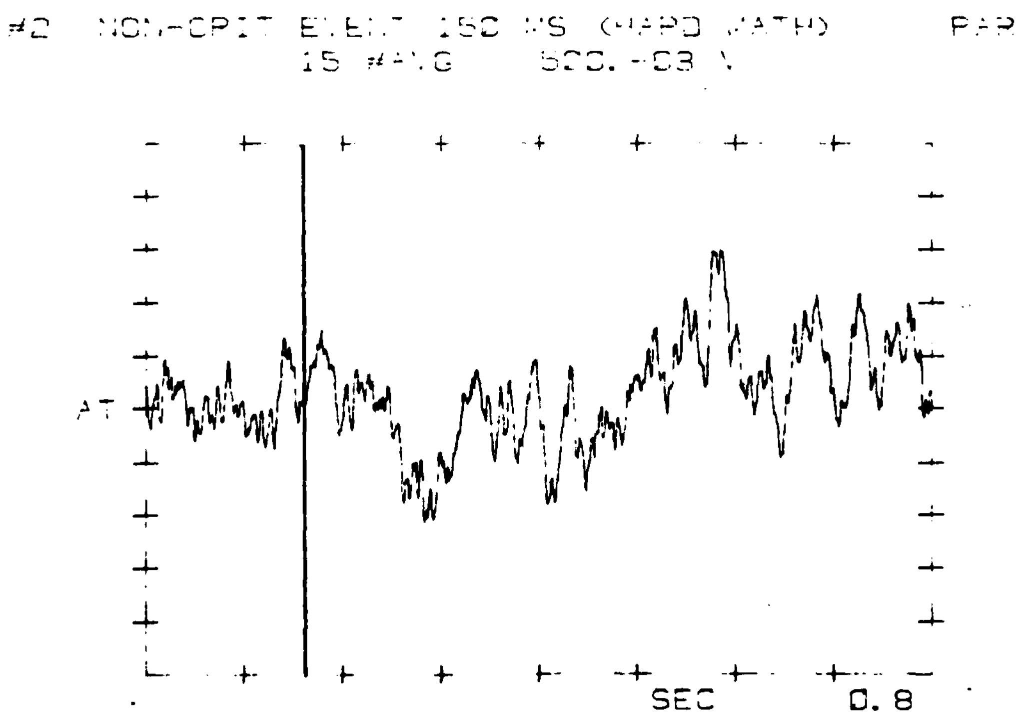
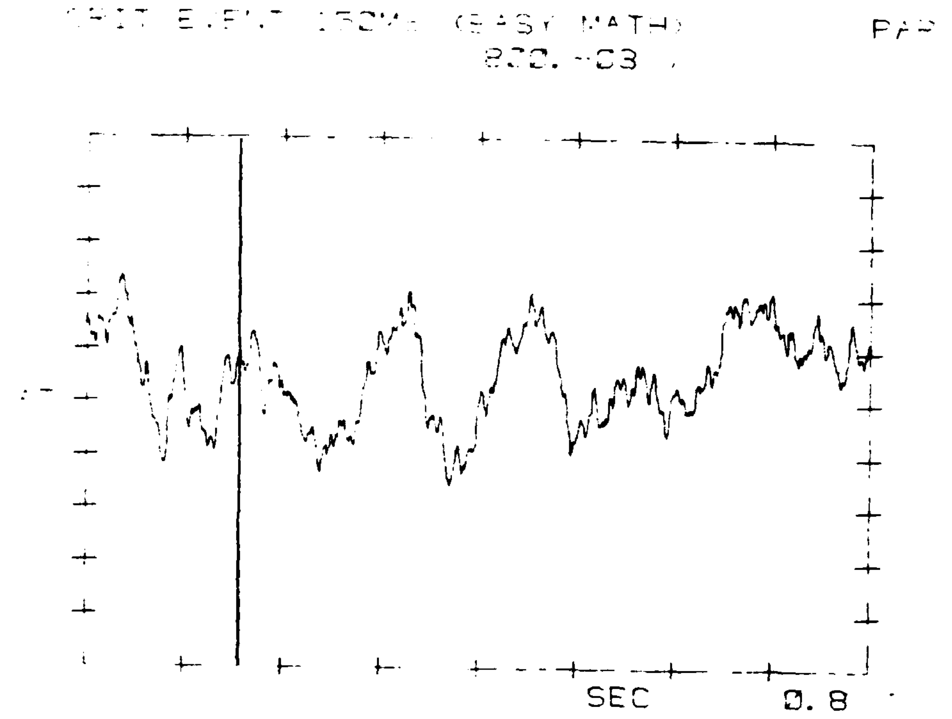


Fig 59. Condition 9/Subject 2



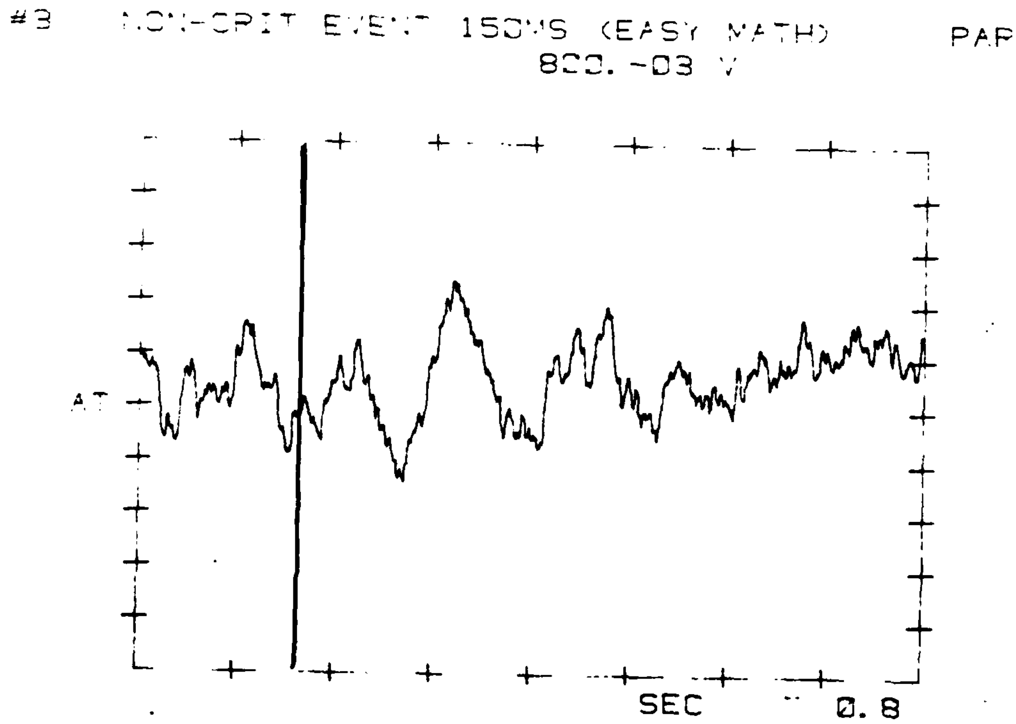
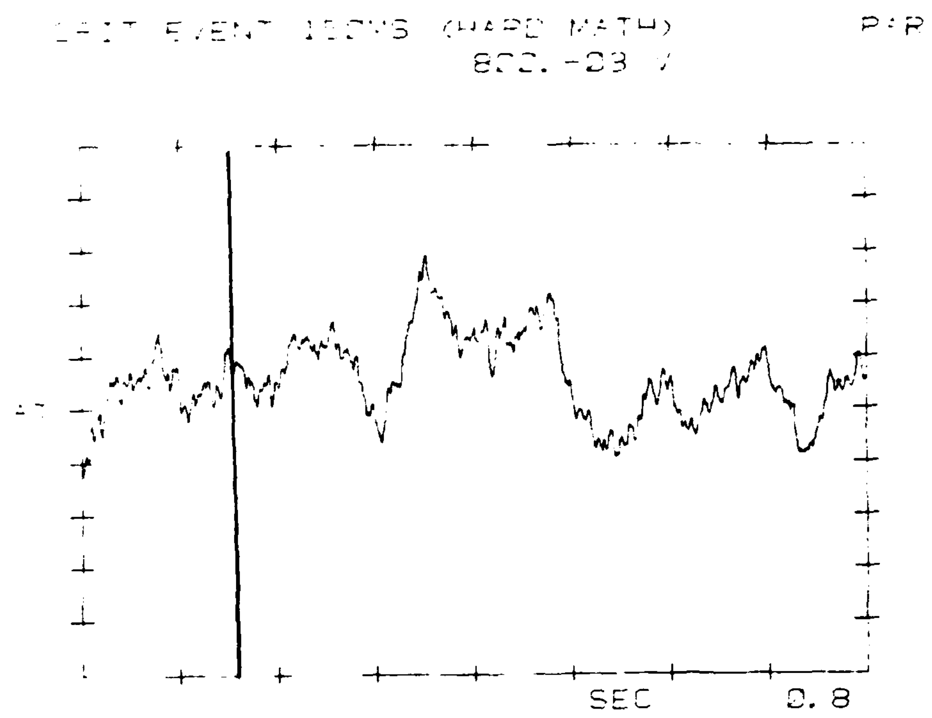


Fig 60. Condition 8/Subject 3



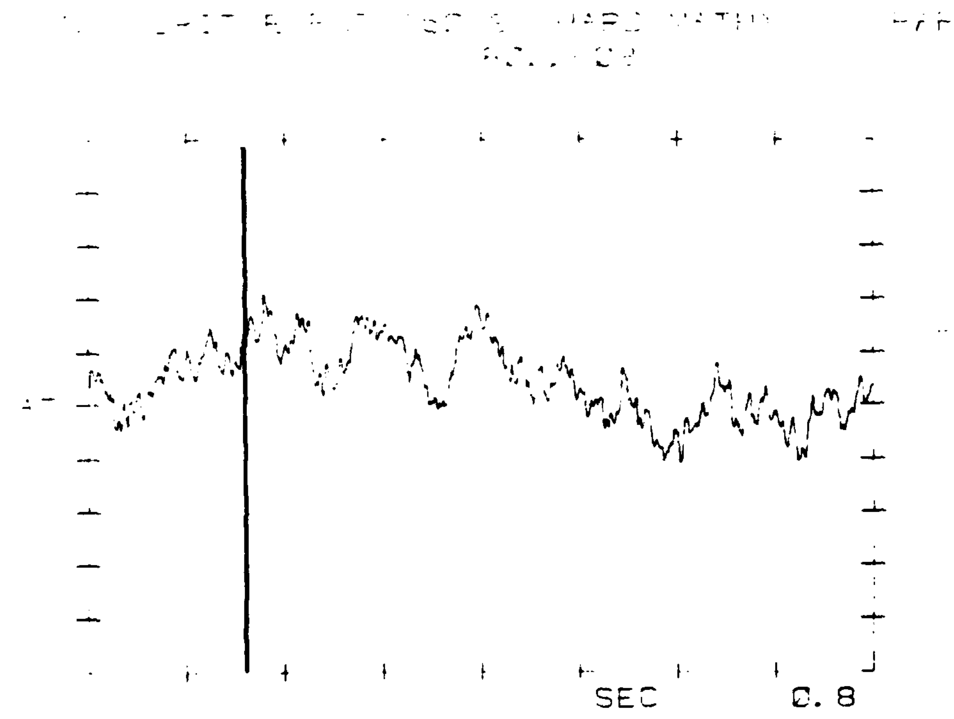
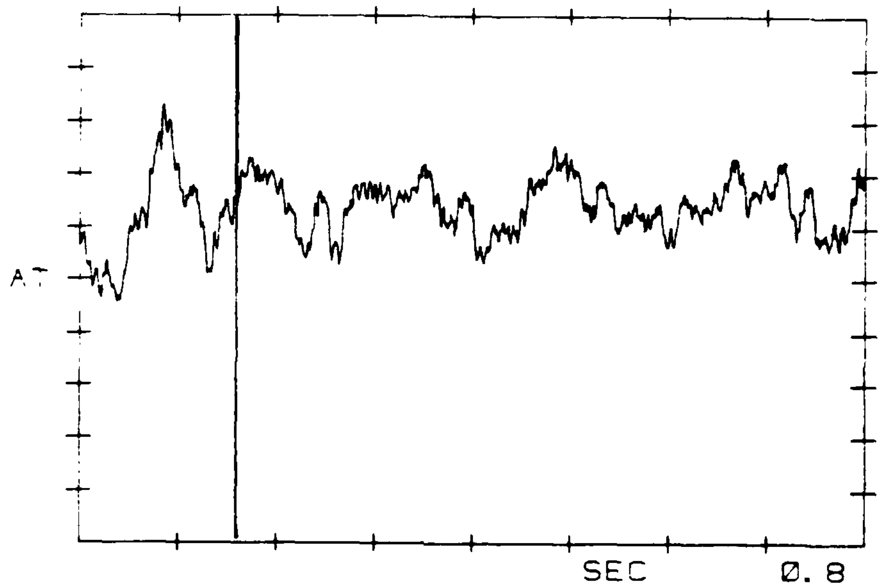


Fig 61. Condition 9/Subject 3

#4 CRIT EVENT 150MS (EASY MATH) PAR
600.-03 V



#4 NON-CRIT EVENT 150MS (EASY MATH) PAR
600.-03 V

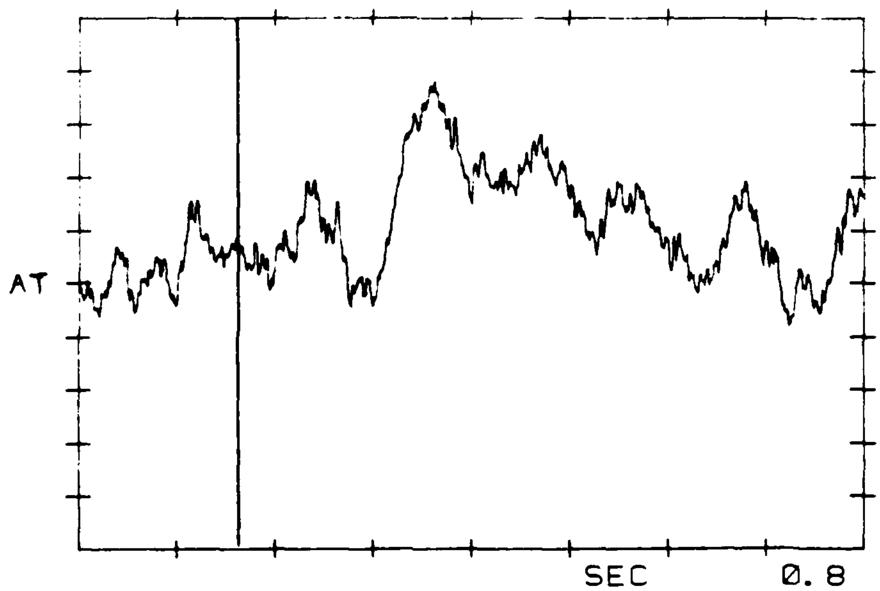
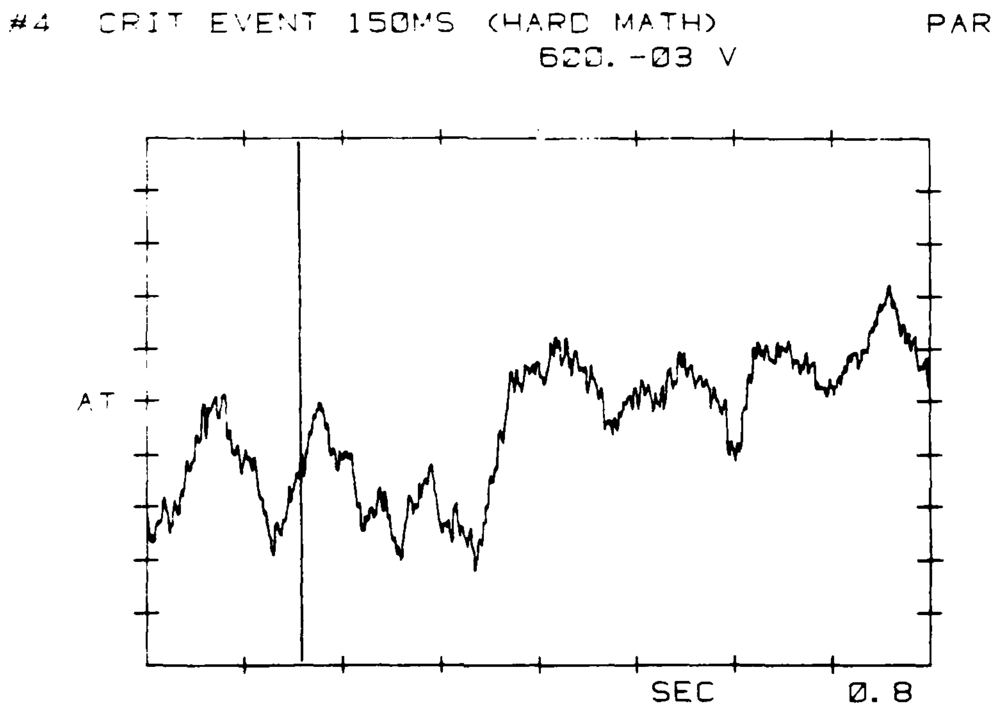


Fig 62. Condition 8/Subject 4



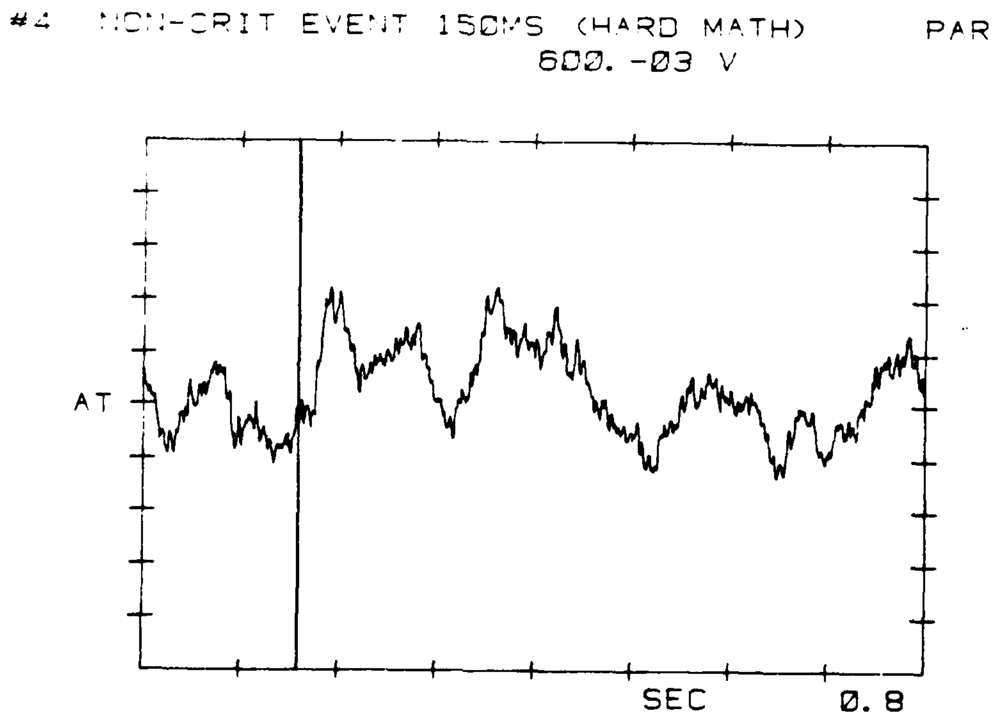
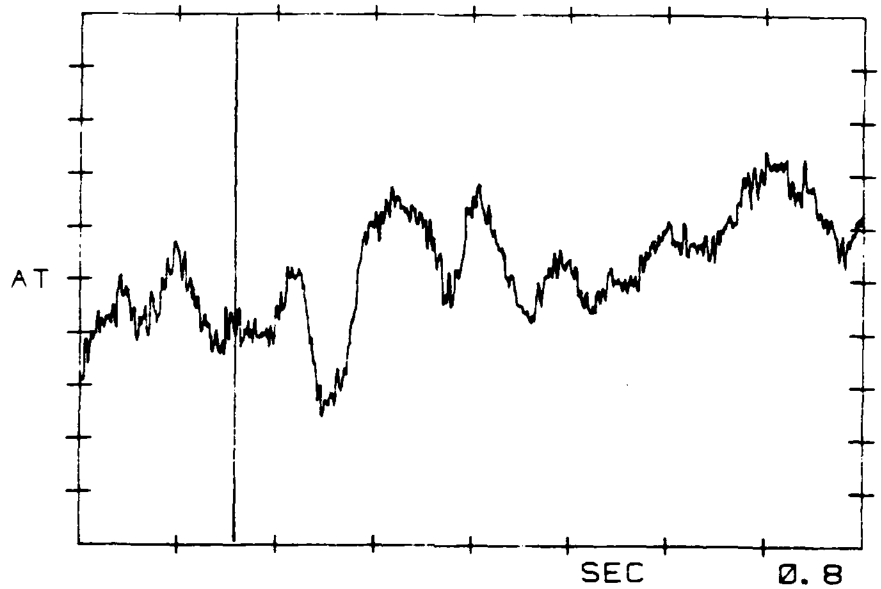


Fig 63. Condition 9/Subject 4

#1 CRIT EVENT 150MS (EASY MONITORING) PAR
500. -03 V



#1 NON-CRIT EVENT 150MS (EASY MONITOR) PAR
500. -03 V

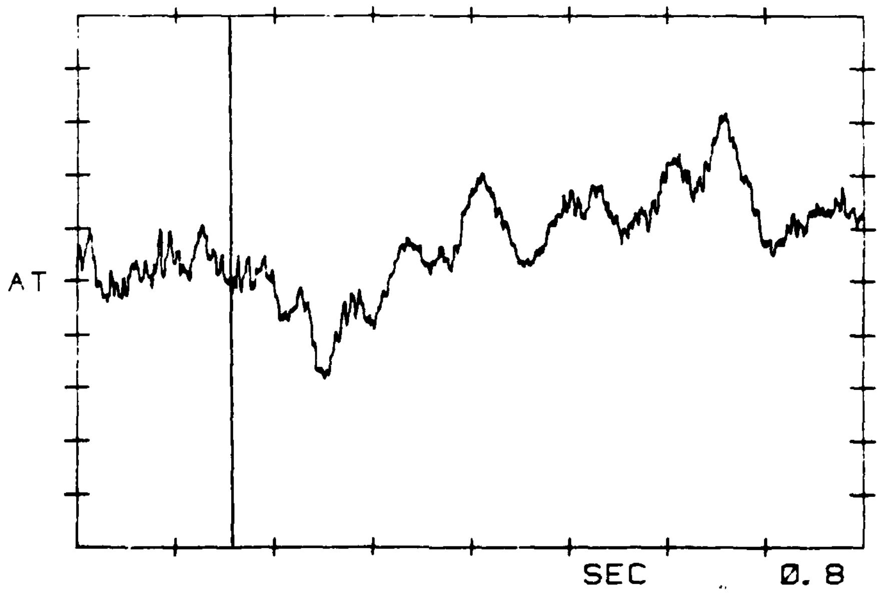
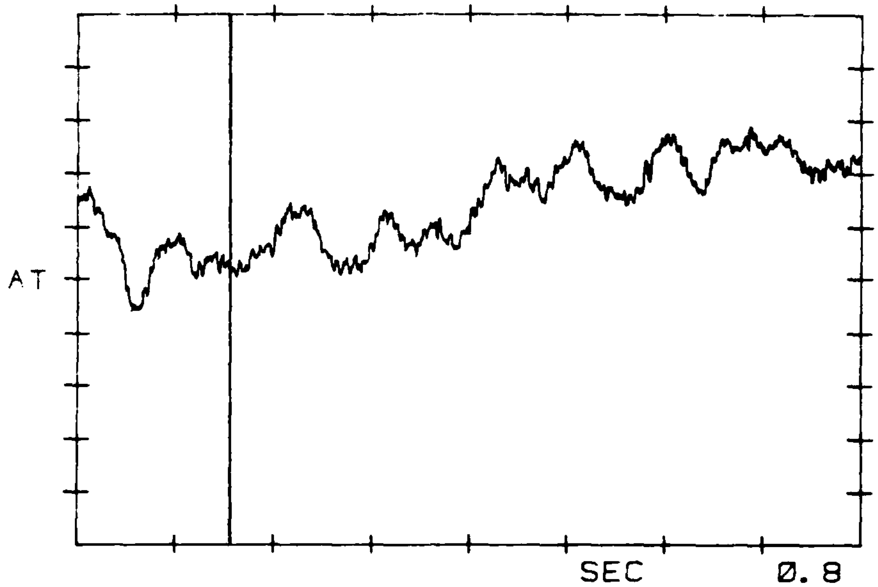


Fig 64. Condition 10/Subject 1

#1 CRIT EVENT 150MS (HARD MONITORING) PAR
500. -03 V



#1 NON-CRIT EVENT 150MS (HARD MONITOR) PAR
500. -03 V

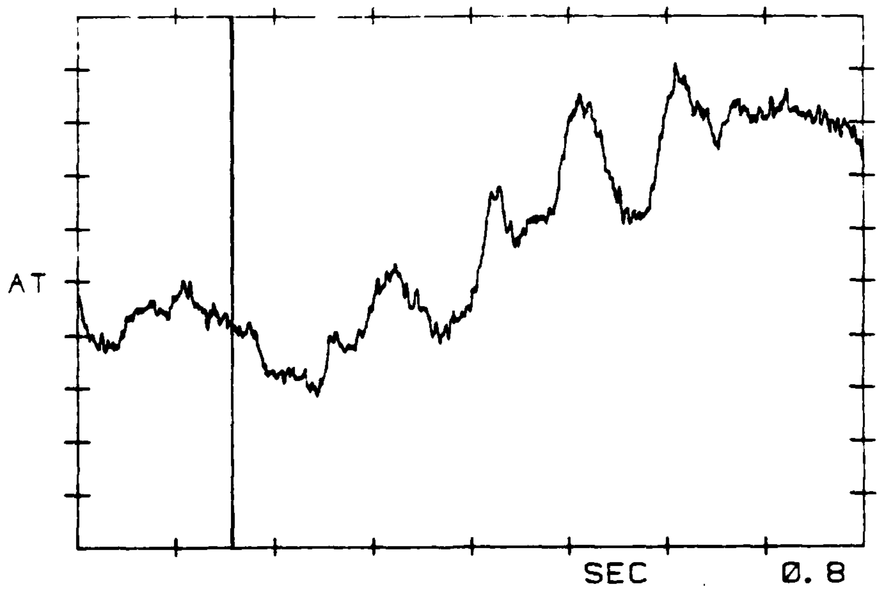
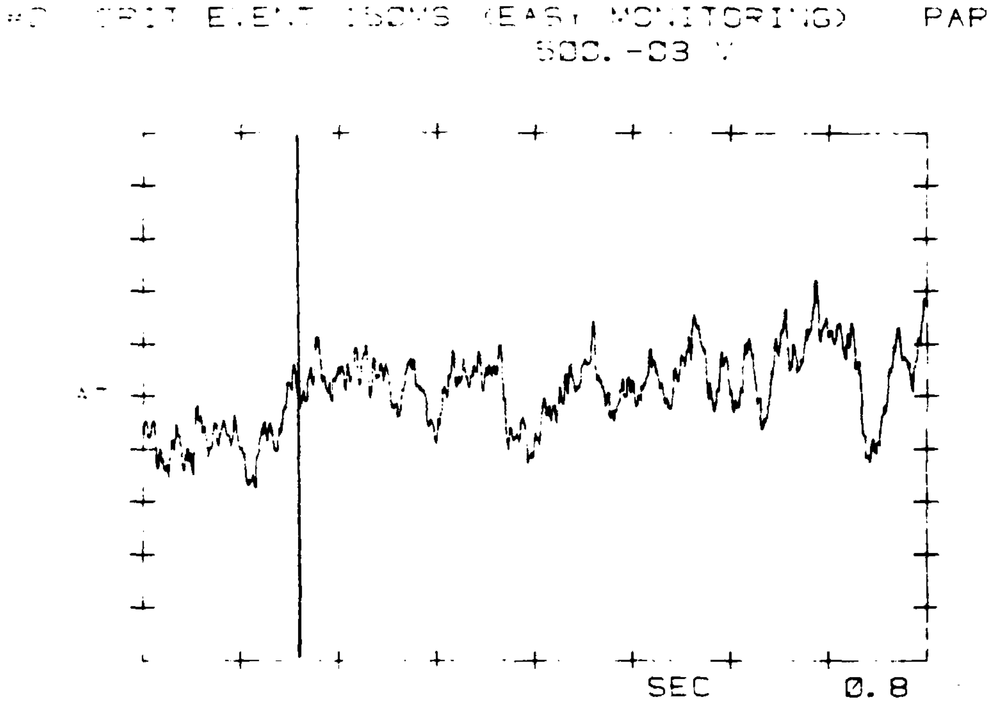


Fig 65. Condition 11/Subject 1



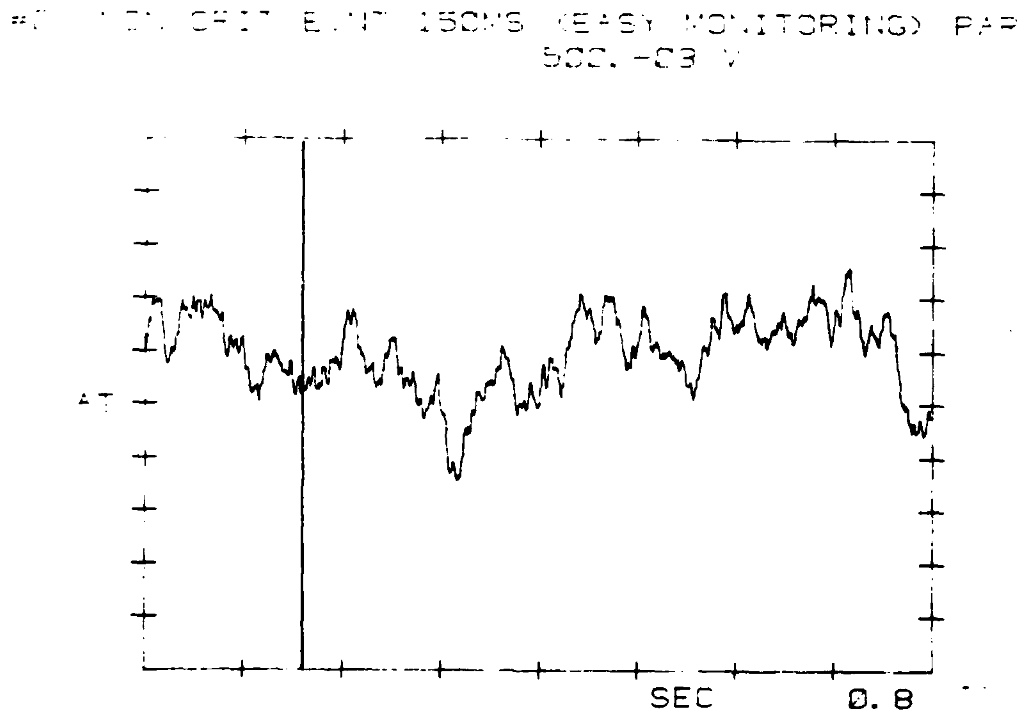
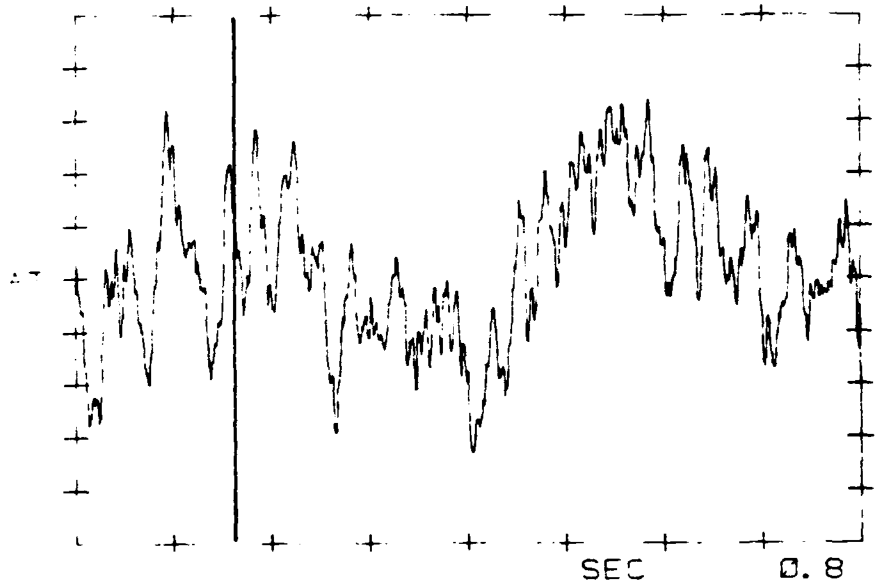


Fig 66. Condition 10/Subject 2

#2 CRIT EVENT 150MS (HARD MONITORING) PAR
500. -03 V



#2 NON-CRIT EVNT 150MS (HARD MONITORING) PAR
500. -03 V

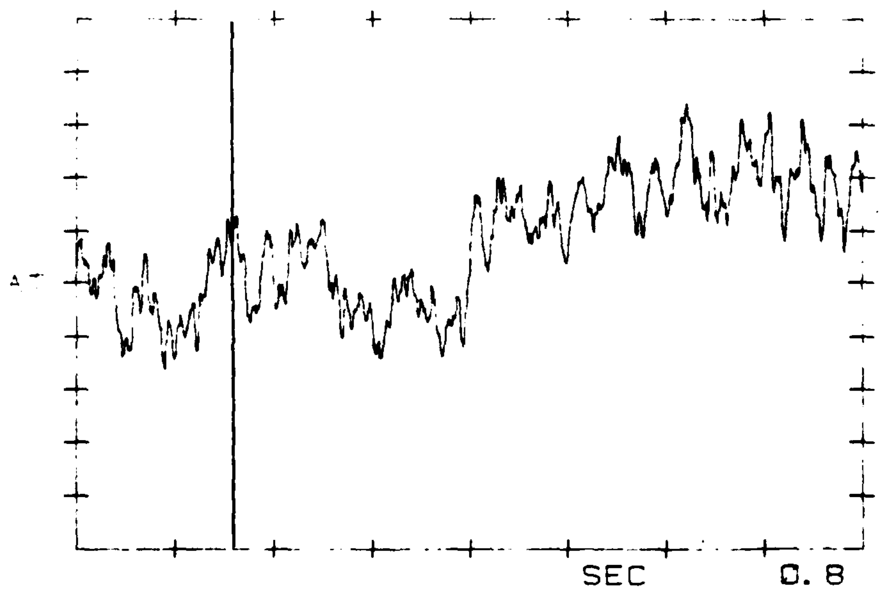


Fig 67. Condition 11/Subject 2

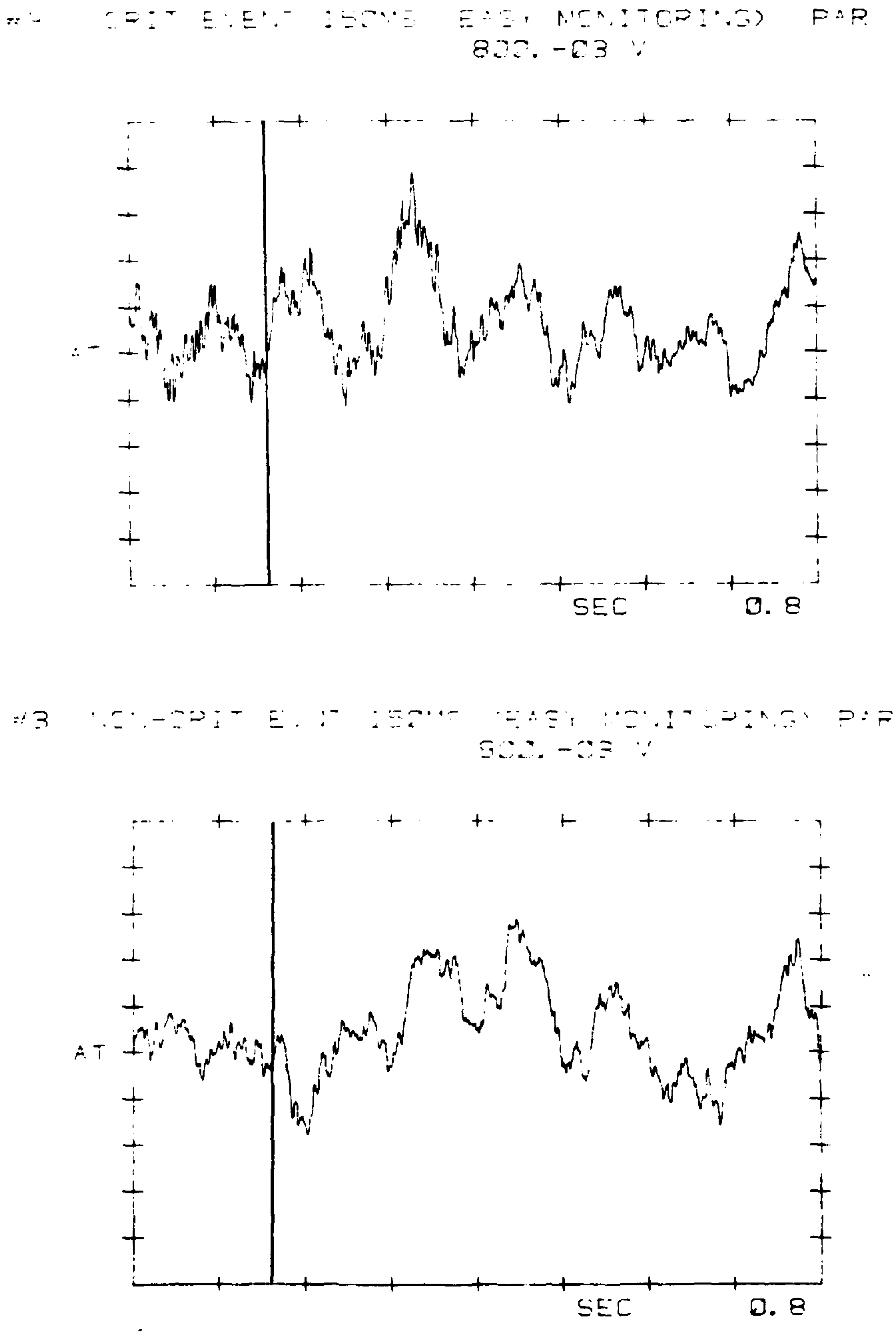
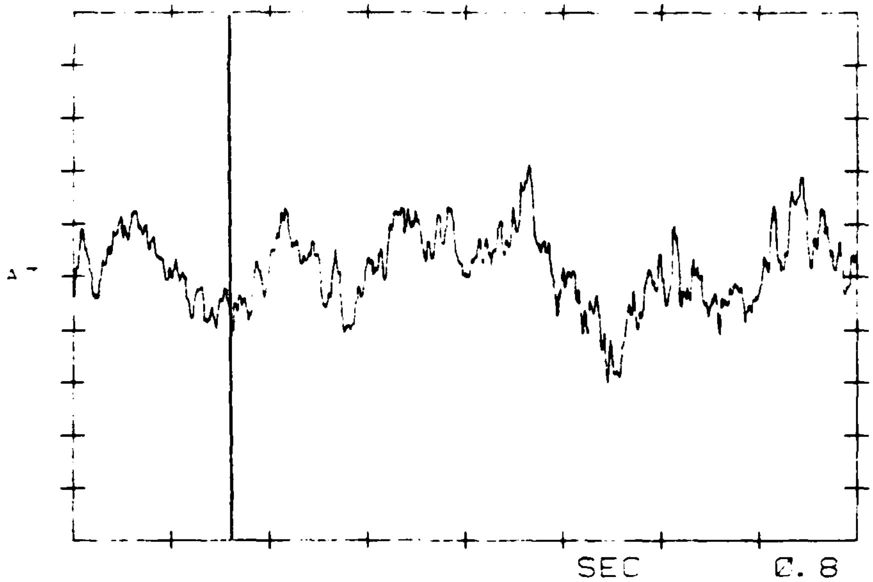


Fig 68. Condition 10/Subject 3

#2 CRIT EVENT 150MS (HARD MONITORING) PAR
800.-03 V



#3 NON-CRIT EVNT 150MS (HARD MONITORING) PAR
800.-03 V

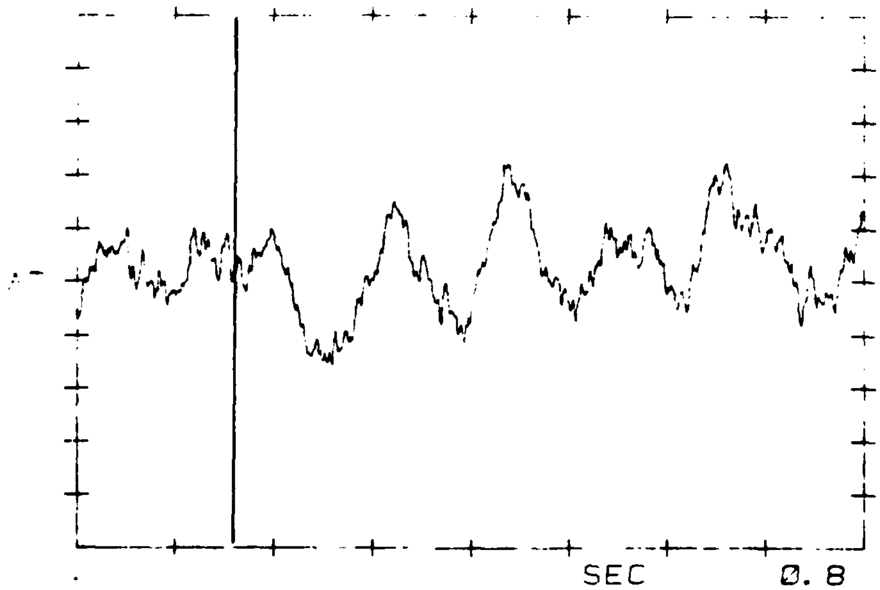
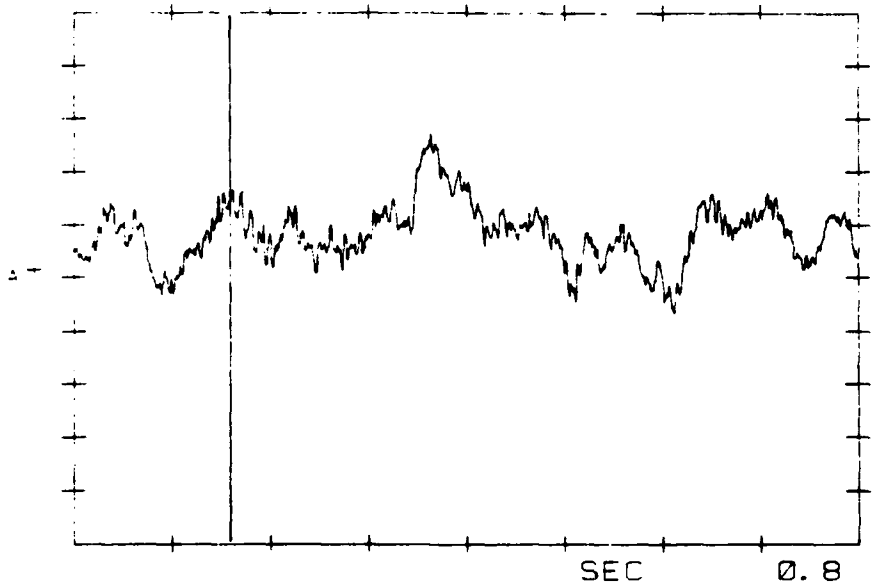


Fig 69. Condition 11/Subject 3

#4 CRIT EVENT 150MS (EASY MONITORING) PAR
600.-03 V



#4 NON-CRIT EVNT 150MS (EASY MONITORING) PAR
600.-03 V

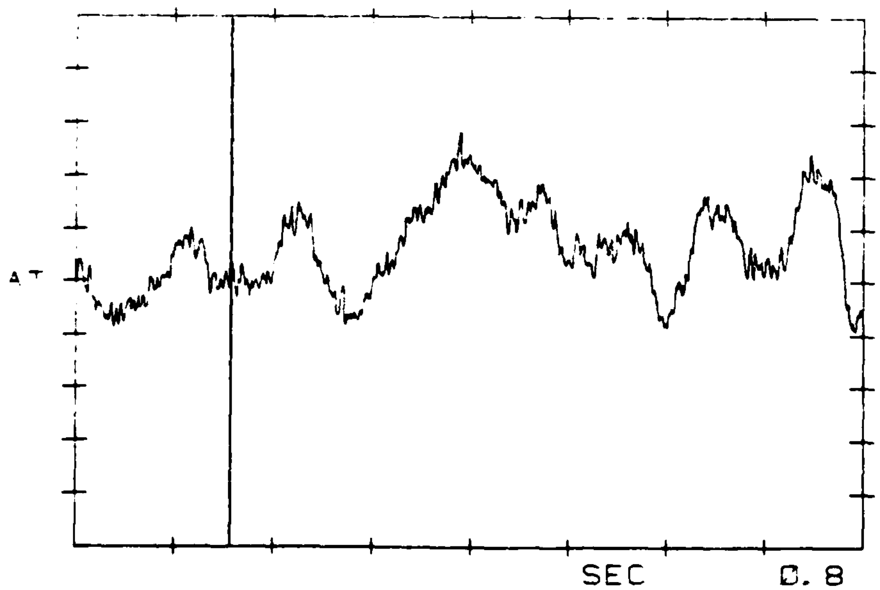
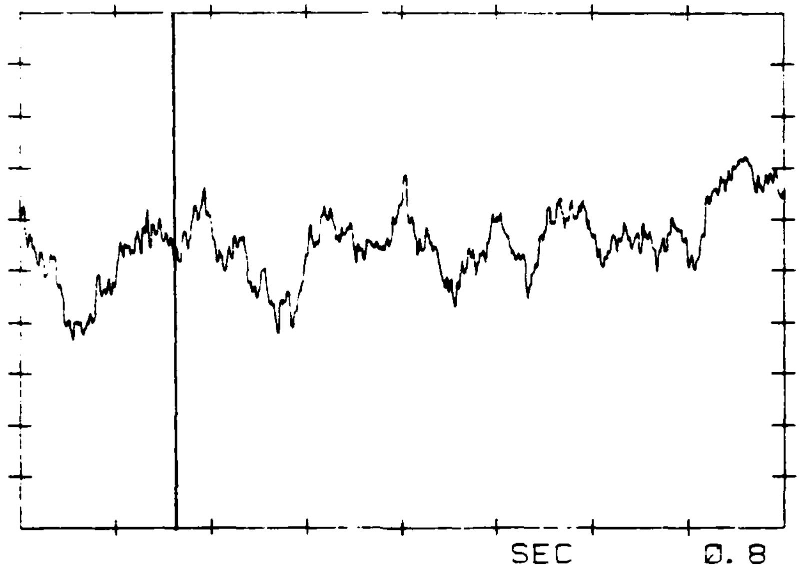


Fig 70. Condition 10/Subject 4

#4 CRIT EVENT 150MS (HARD MONITORING) PAR
6ØØ.-Ø3 V



#4 NON-CRIT EVNT 150MS (HARD MONITORING) PAR
6ØØ.-Ø3 V

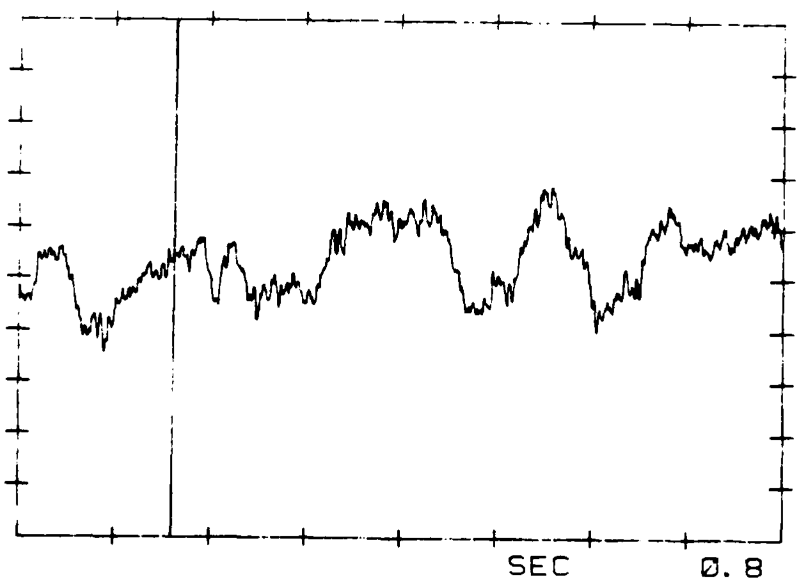


Fig 71. Condition 11/Subject 4

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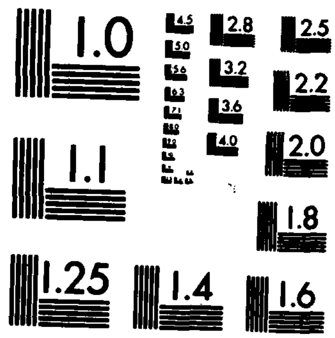

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Abstract

An experiment was designed to investigate late positive components of the transient evoked potential elicited by detection of four consecutive ones within a pattern of seven binary digits. Areas of investigation included spatial distribution, motor response effects, stimulus duration effects, possible contingent negative variation effects, components of the event which immediately preceded the critical event, and value as a workload metric. Electrodes recorded EEG at the parietal, central, and frontal midline scalp locations with opposing mastoids used for reference and ground. Reaction times and response accuracy were also recorded.

Though equipment failure precluded any significant statistical analysis, descriptive observations of the data provided useful guidance for future research. A prominent, positive component in the P5ØØ latency range was elicited by the critical event stimulus. Its spatial distribution generally showed a parietal maximum and a frontal minimum. The additional presence of a P3ØØ appears possible, but could not be confirmed. The prominent P5ØØ component became less apparent when stimulus duration approached the 1.5 to 3.Ø second interstimulus interval. No other significant effects were observed. The critical event was also presented as a secondary task combined with each of three primary tasks. Performance scores, reaction times, and evoked potentials indicated the critical event detection task was too intrusive to be a useful workload metric.

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